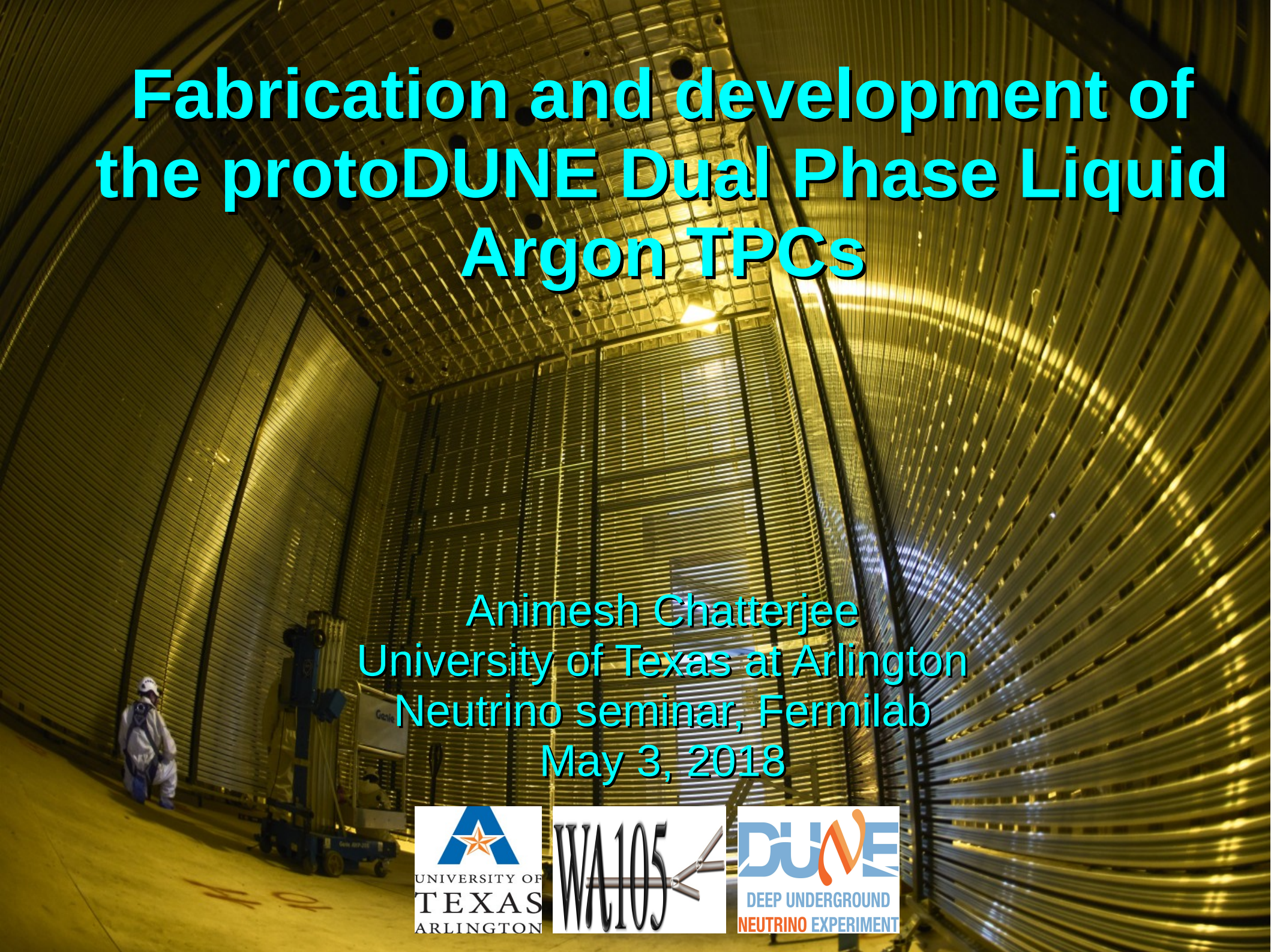
Fabrication and development of the protoDUNE Dual Phase Liquid Argon TPCs



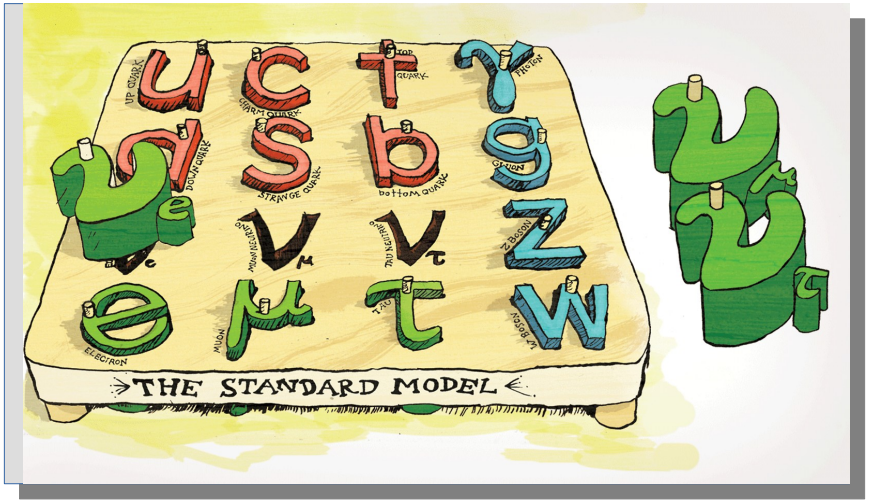
Animesh Chatterjee
University of Texas at Arlington
Neutrino seminar, Fermilab
May 3, 2018

Outline

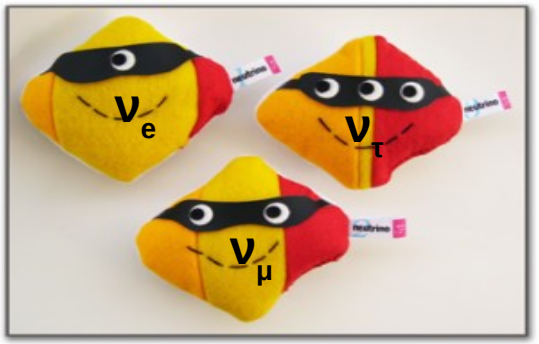
- **Motivation**
  - → LArTPC
  - → Dual-Phase LArTPC
- **LArTPC Dual-Phase concept**
- **protoDUNE Dual-Phase detector**
  - → Detector design and components
  - → Production status
  - → Schedule and plan
- **3x1x1 m^3 LArTPC Dual-Phase pilot detector**
- **Conclusions**

Motivation: Neutrino detection

- In the Standard model **neutrinos** are neutral leptons that only interact via the weak force



- Three flavors of neutrinos (experimentally observed)



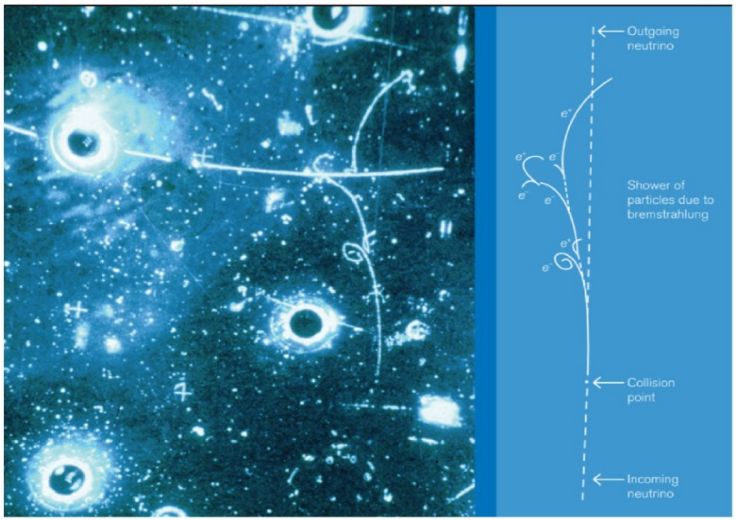
- Neutrinos are very elusive, making experimental inquiry a tough job

Need massive detector with very good understanding about signal and background

Motivation : Liquid Argon Time Projection Chamber (LArTPC)

Key for neutrino detection : large mass and full imaging of the interaction

- In order to improve sensitivity by reducing backgrounds and improving resolution, would like to have a neutrino detector with the image quality of a bubble-chamber with the following properties
  - → Scalable
  - → Fast readout
  - → Not very expensive



Are there any such technology ?
Yes ! Liquid Argon Time Projection Chamber

Liquid Argon TPC for neutrino physics

- The Liquid Argon Time Projection Chamber is the successful marriage between the "gaseous TPC"(David Nygren now at UTA) and "the liquid argon Calorimeter" to obtain

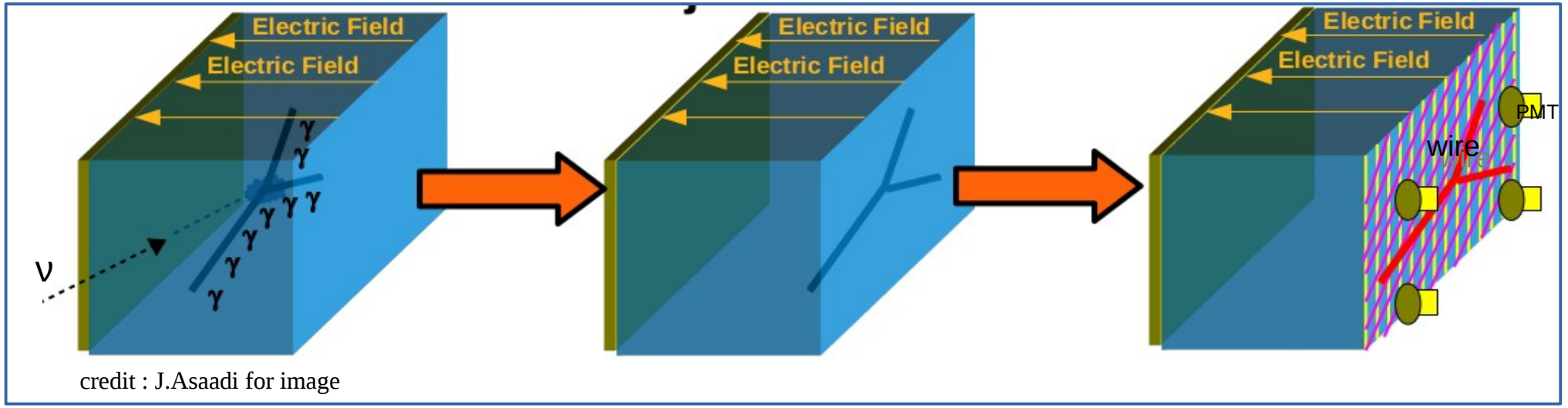
→ very fine grained 3D tracking
→ excellent particle identification capability
→ precise calorimetric energy reconstruction

- After many decades of pioneering R&D, the technology has matured into a fundamental and necessary technique to address the particle physics challenges of the 21st century. It has the potential to be the tool to discover new phenomena, such as:

*** Neutrino oscillations, Mass ordering of neutrinos, octant of θ_{23}**
*** discovery of CP violation in the lepton sector**
*** existence of sterile neutrinos**
*** the unambiguous observation of nucleon decay**
*** the possible observation of unpredicted rare events**

How LArTPC Works?

- Neutrino (Charged particle) interaction in LAr produces ionization and scintillation light
- Drift the ionization charge in a uniform drift volume
- Readout the charge and light produced using wires (anode) and PMTs



credit : J.Asaadi for image

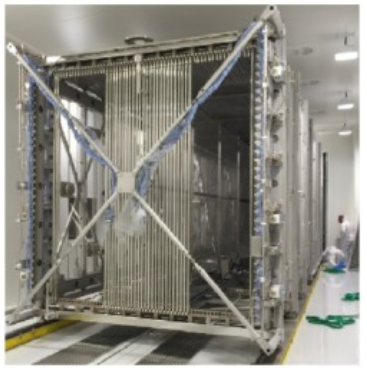
Why LAr ?

* Dense (40% more than water)
* Abundant (1% of the atmosphere)
*Ionizes easily (55,000 electrons/cm)
* High electron lifetime

LArTPC exposed to neutrinos

ICARUS T-600 @ CNGS (2010-2012, 760 tons LAr)





Argoneut @ FNAL (2009-2010, 240 kg LAr)



MicroBooNE @ FNAL (2015-ongoing , 170 tons LAr)



LArTPC exposed to neutrinos

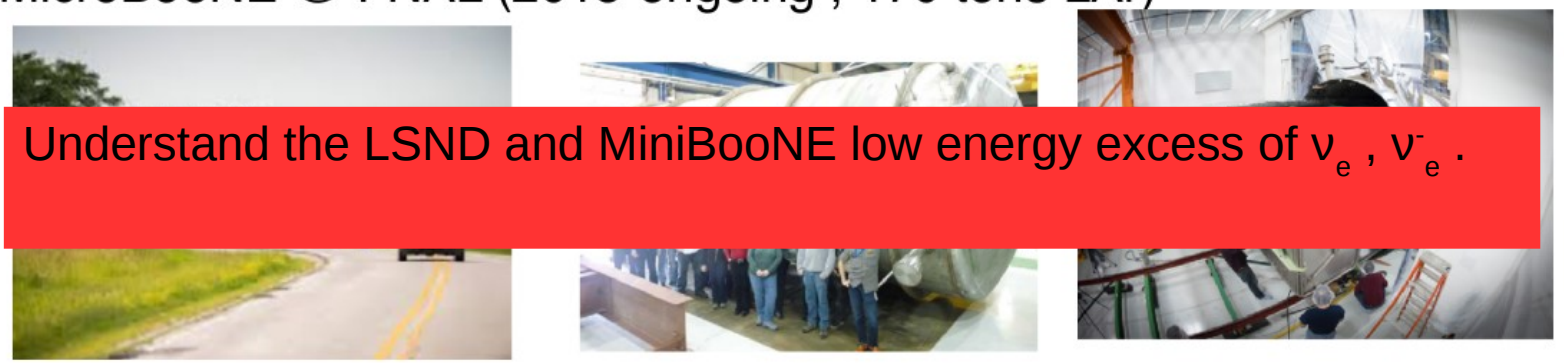
ICARUS T-600 @ CNGS (2010-2012, 760 tons LAr)

largest TPC operated in a neutrino beam CNGS high energy neutrinos (~17 GeV) neutrino event reconstruction, neutrino time of flight, long term operation, purity,..

Argoneut @ FNAL (2009-2010, 240 kg LAr)

small TPC low energy neutrinos. inclusive ν_μ x-section, ν_μ and ν^-_μ coherent pion production cross-sections on argon, study of two-proton events, low energy νe interactions,..

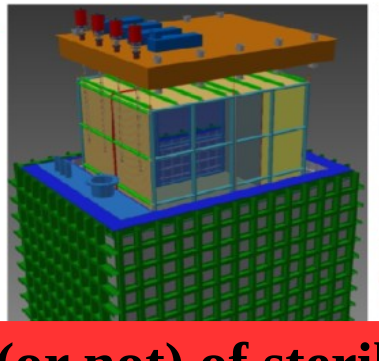
MicroBooNE @ FNAL (2015-ongoing , 170 tons LAr)



Understand the LSND and MiniBooNE low energy excess of ν_e , ν^-_e .

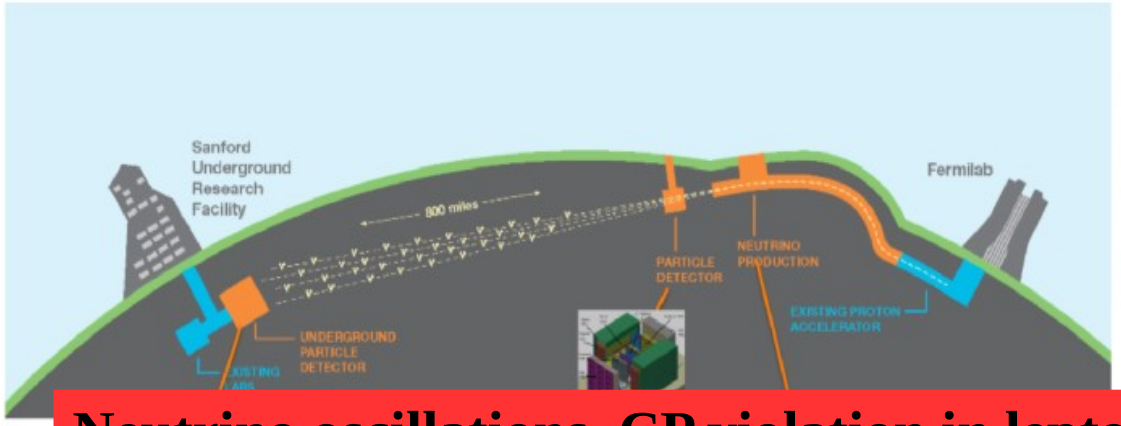
LArTPC for neutrino physics : planned

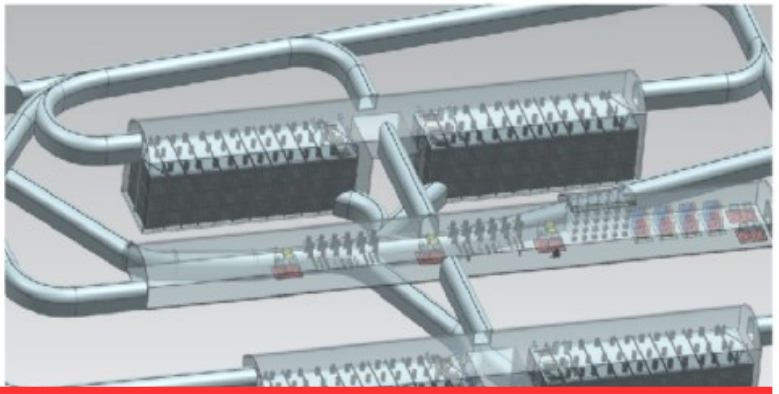
Planned @FNAL short baseline MicroBooNE + SBND + ICARUS



Search for the existence (or not) of sterile neutrino

Planned DUNE : FNAL to SURF





Neutrino oscillations, CP violation in lepton sector, nucleon decay, observation of unpredicted rare events

DUNE Overview

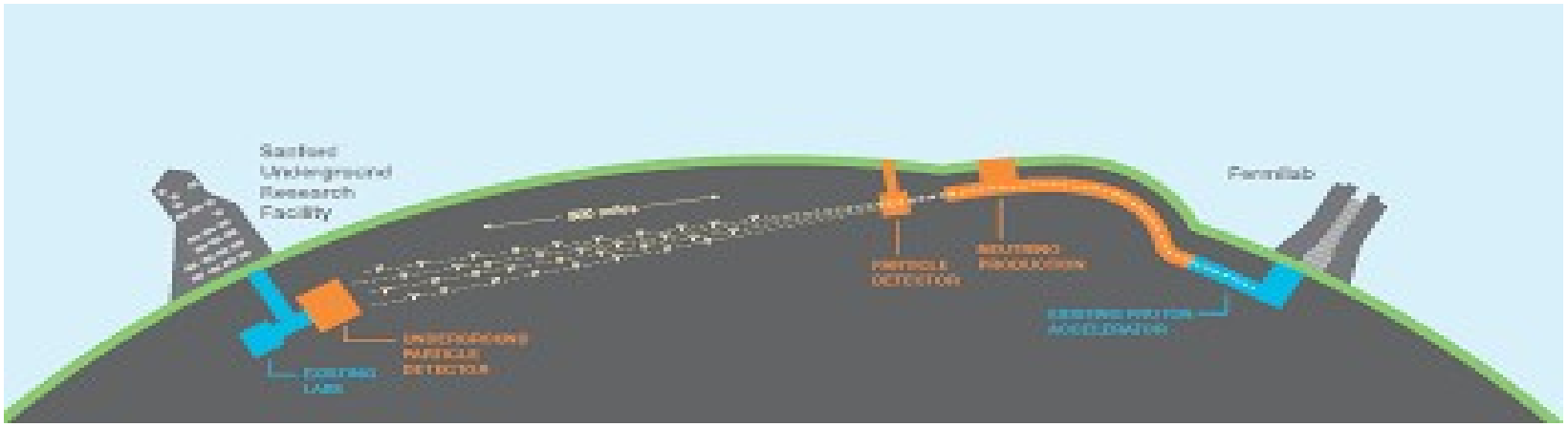
- The **Deep Underground Neutrino Experiment (DUNE)** is a leading edge, international experiment for neutrino science and proton decay

Features of DUNE:

- → **1300 km baseline : "LBL"**
- → **Most intense neutrino beam : "LBNF"**
- → **Large (40kt) LArTPC far detector and near detector**
- → **Far detector 1.5 km underground**

Primary Physics goals :

- → **ν oscillations MH, δcp, θ_{23}**
- → **Physics beyond standard model**
- → **Nucleon decay**
- → **Supernova burst neutrinos**



DUNE prototype LArTPC detectors are under construction at CERN

***** protoDUNE Single Phase LArTPC

***protoDUNE Dual Phase LArTPC**

Motivation:The Dual-Phase LArTPC

- **Neutrino Experiment requires massive detectors → Very long drifts**
- **Long drifts requires ultra high purity → charge attenuation**
- **No charge amplification in single phase**

The Dual-Phase LArTPC :

- **The Dual-Phase (DP) LArTPC refers to the extraction of ionization electrons at the interface between liquid and gaseous argon and their amplification and collection at the gaseous phase**

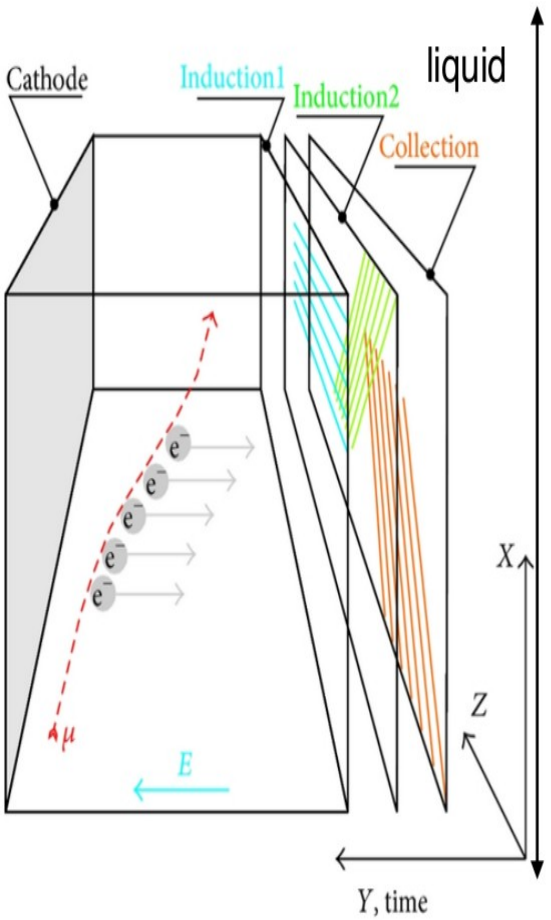
- **<u>Key-feature</u>**

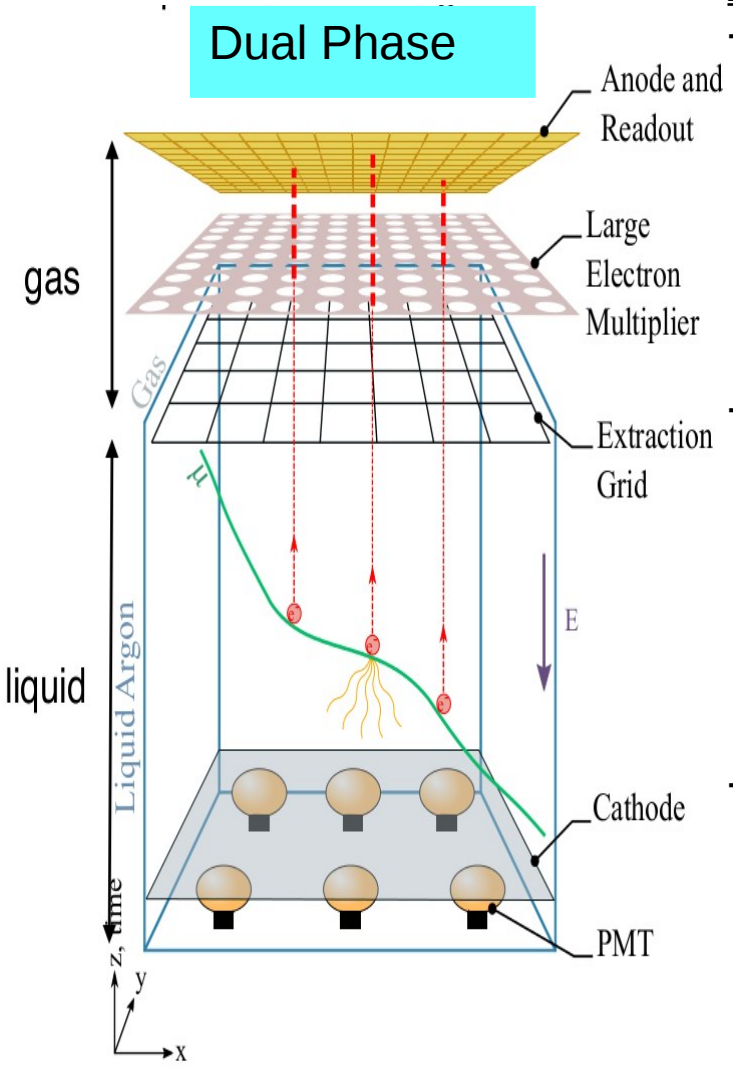
  → Amplification of the signal by charge avalanche in the gas phase
  → Large signal/noise ratio
  → Allow constructing detectors with large drift
  → overall good image quality

The Dual-Phase Concept

Single Phase

- Ionization and collection in the same phase
- Read out by wires, one collection view and one or more induction view
- No amplification of the initial ionization signal





Dual Phase

- Ionization in liquid argon and collection in the gaseous phase
- Extraction of the electrons to the gas phase from the liquid level
- Avalanche multiplication of the electrons in the pure argon gas

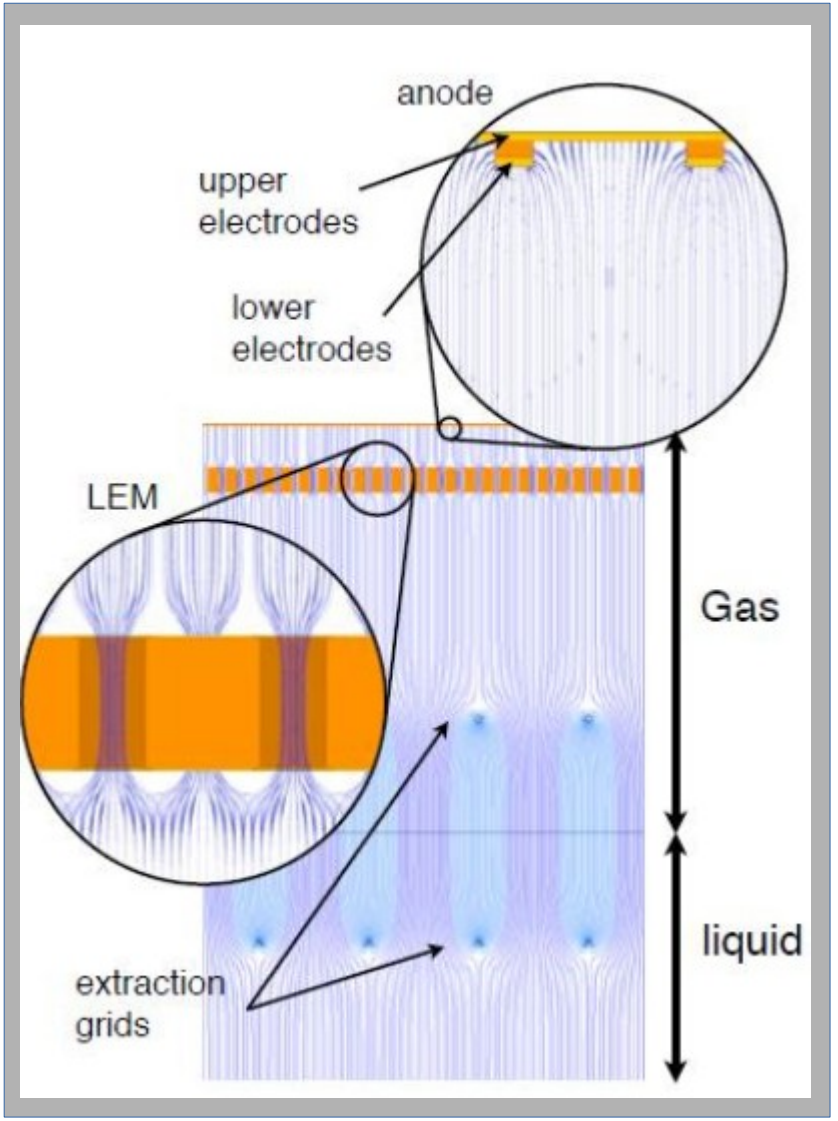
The Dual Phase Concept

Charge Collection on anode readout : 2 orthogonal views (no induction plane)

Charge Multiplication : LEM (Large Electron Multiplier)

Electron extraction from liquid to gas phase through a grid

Ionization electron drifts towards the liquid argon surface



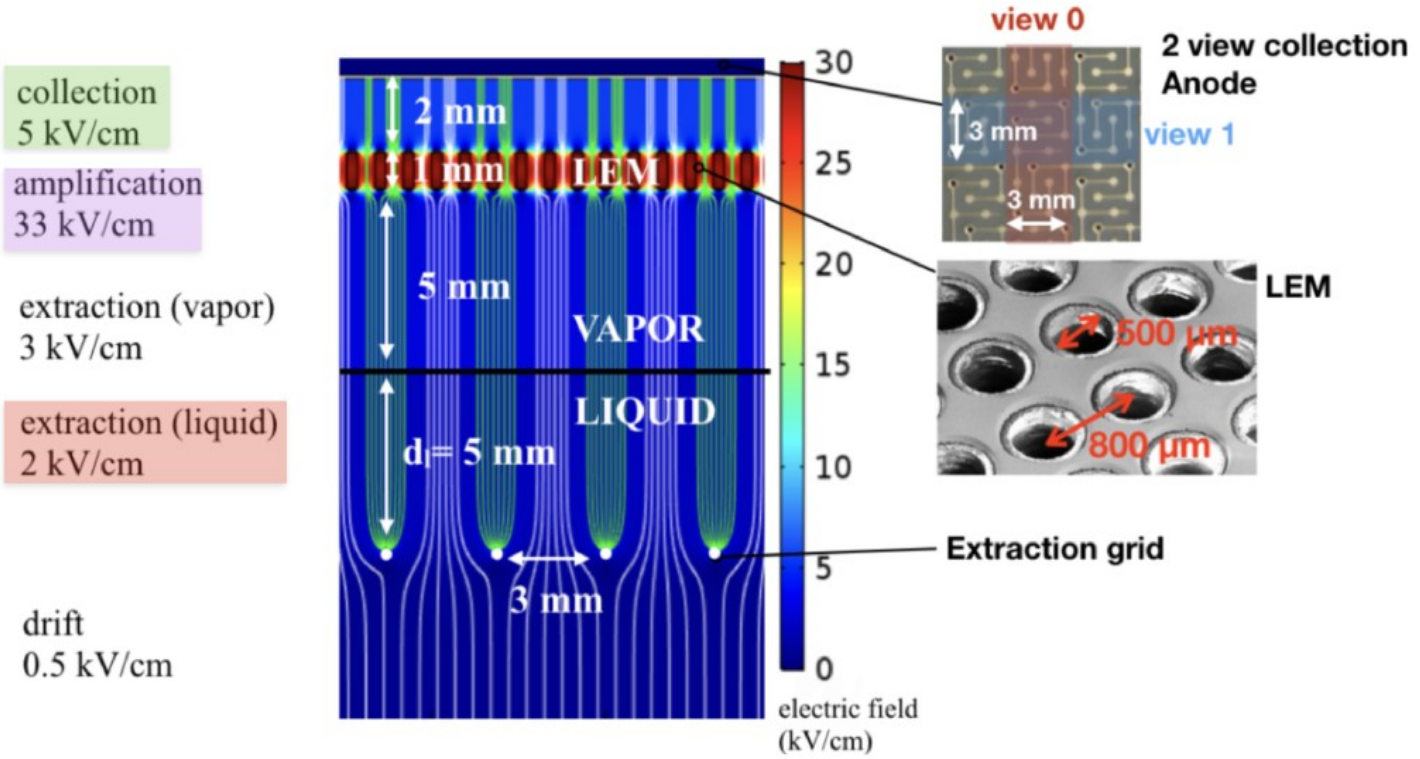
Amplification, readouts with only collection views on PCBs (no need for complex deconvolution algorithms)

Gain of Dual-Phase LArTPC

$\varepsilon_{collection}$= fraction of electrons transferred from LEM to anode (inefficiencies essentially due to electrons collected on top electrode of LEM)

G_{LEM}= multiplication factor of the electrons x transparency of its bottom electrode

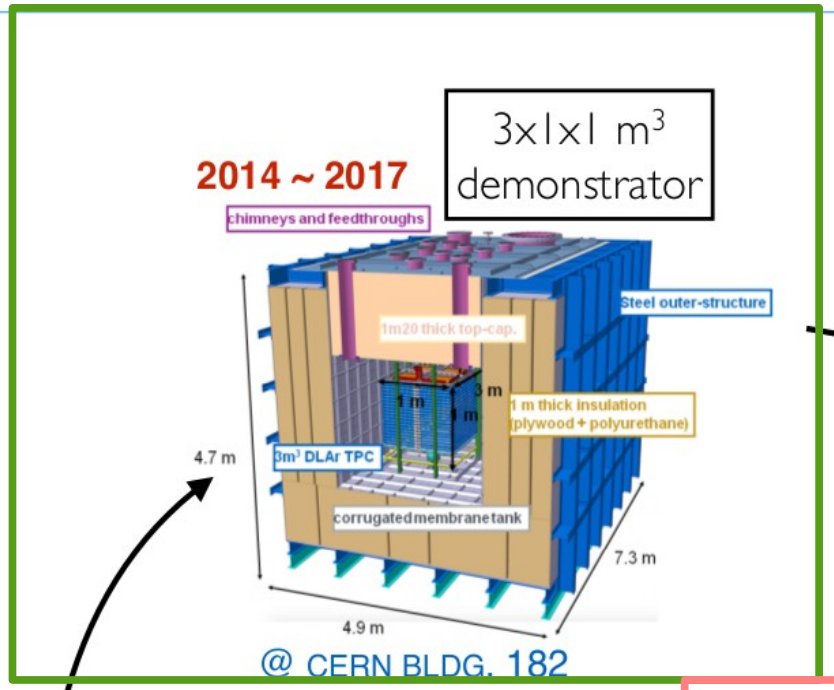
$\varepsilon_{extraction}$= fraction of electrons which are extracted from the liquid (inefficiencies essentially due to transparency of grid)

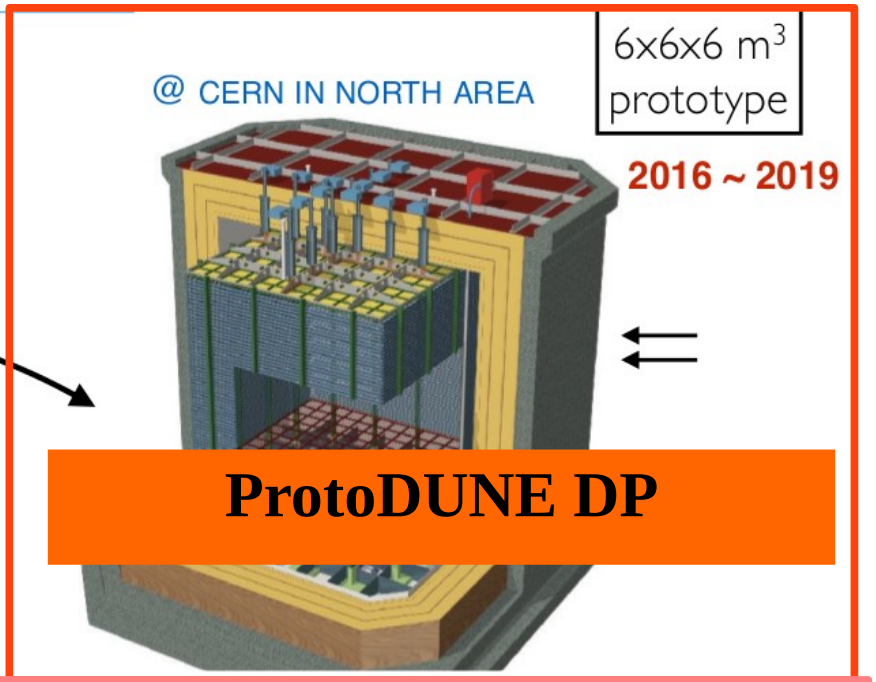


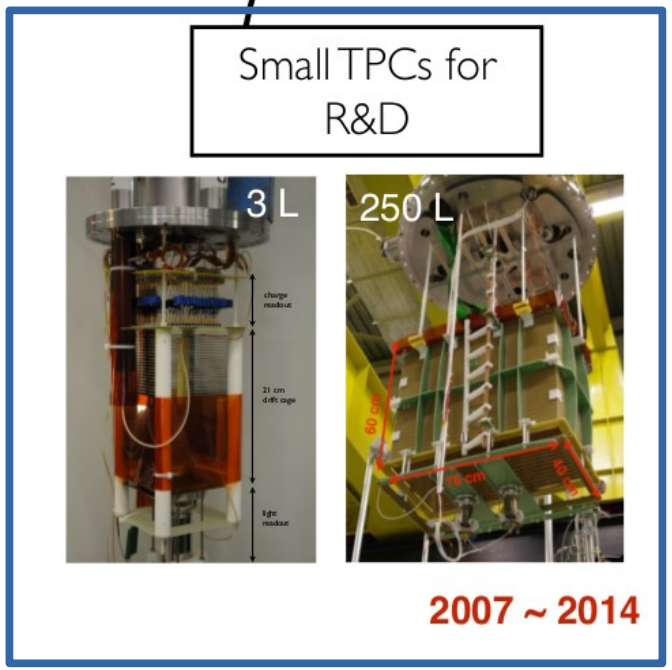
Effective Gain = Extraction Efficiency X LEM Amplification X Collection Efficiency

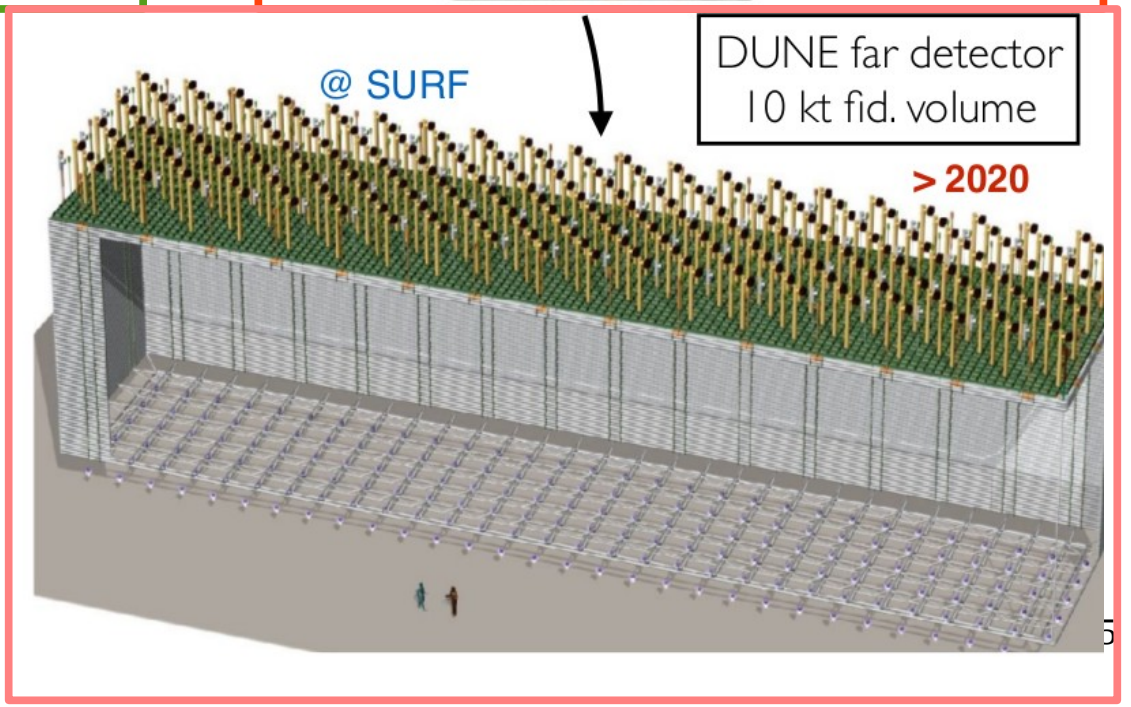
$G_{eff} = \varepsilon_{extr} \times G_{LEM} \times Ecoll$

Journey of Dual Phase LArTPC

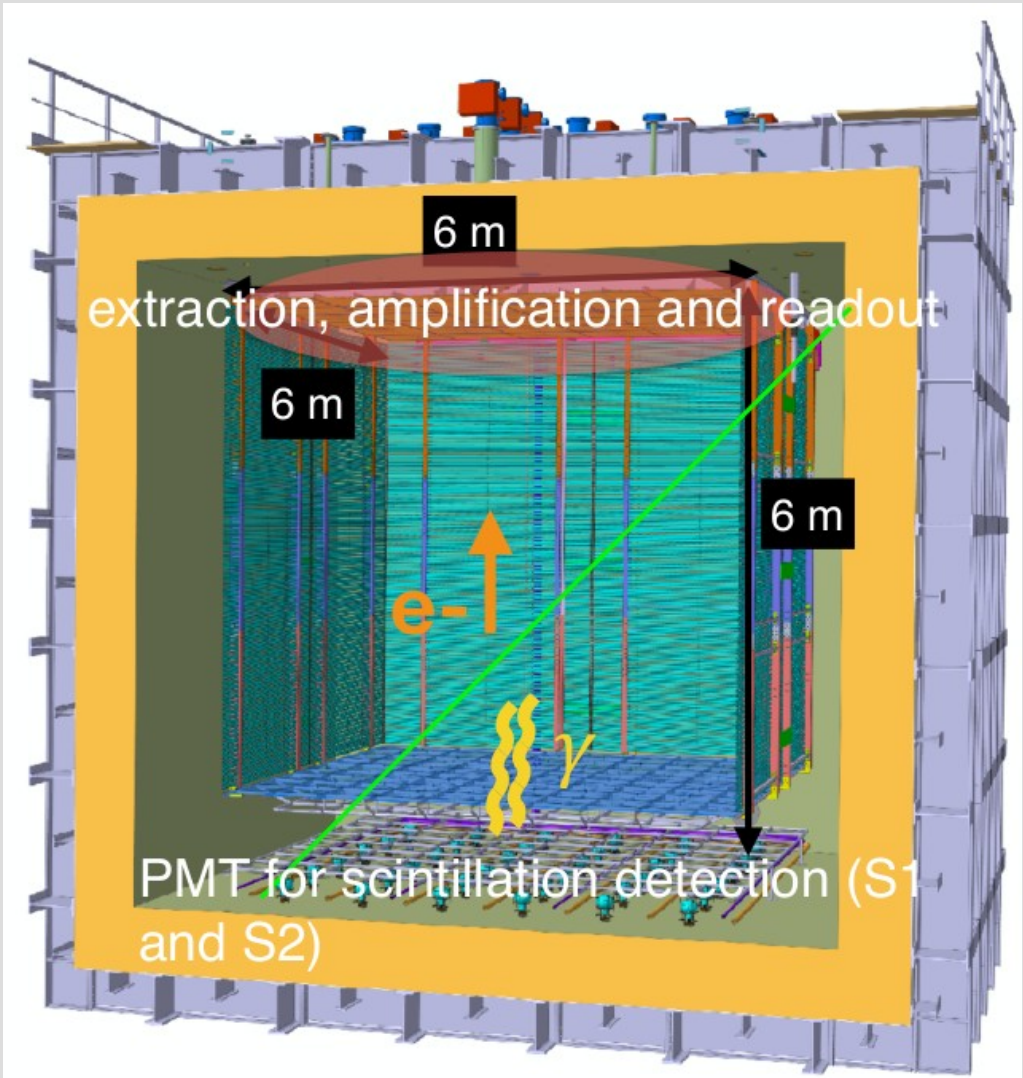








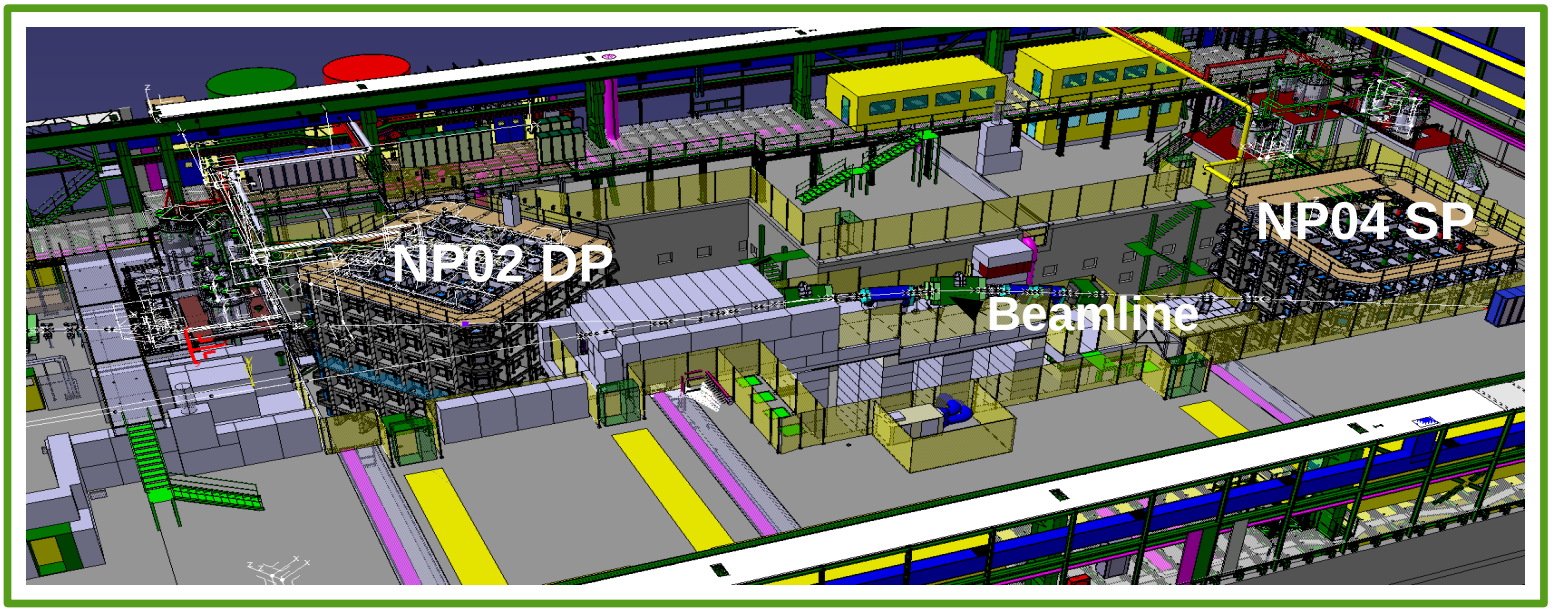
The WA105/NP02 protoDUNE Dual Phase LArTPC



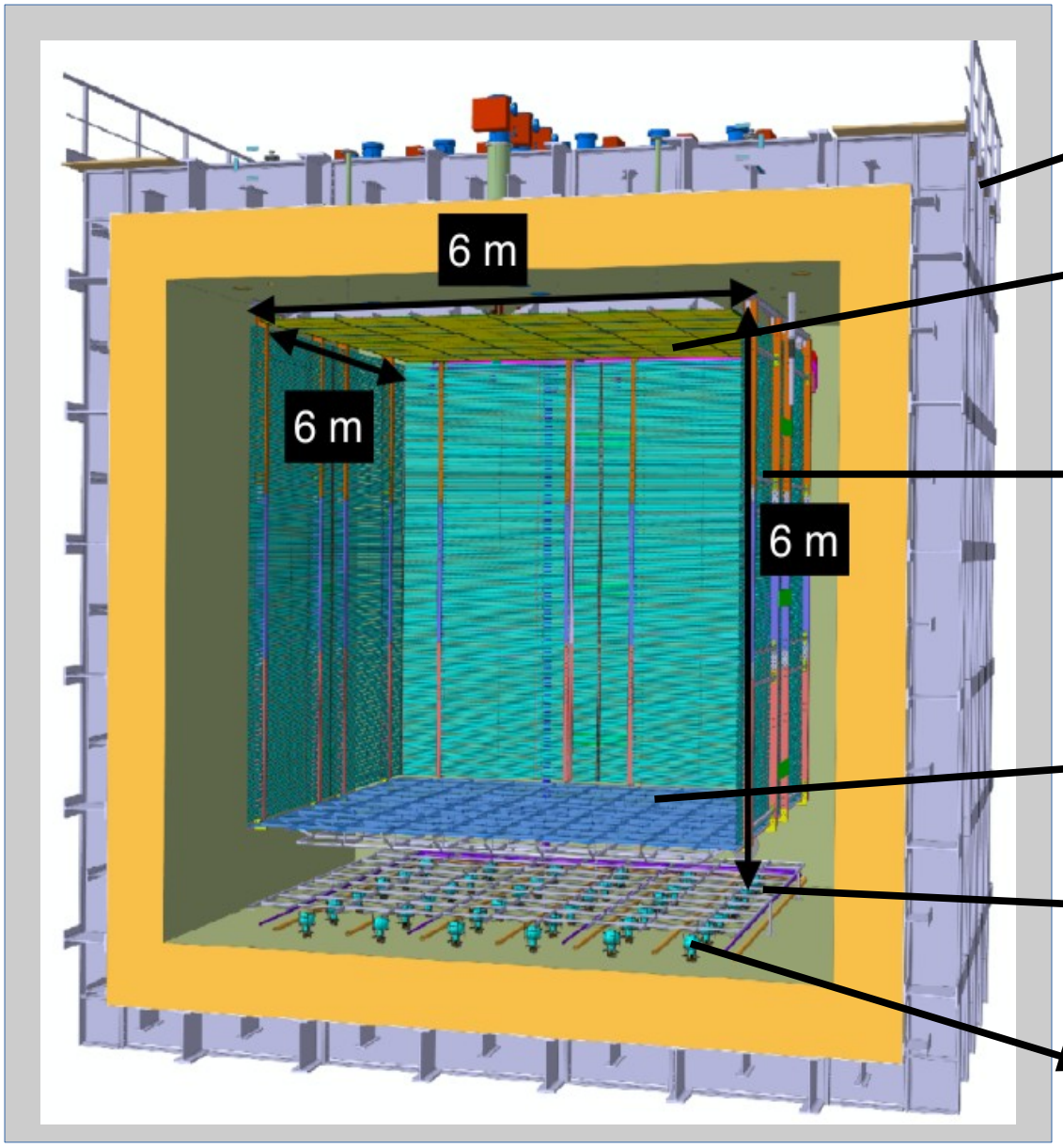
Physics program :

- **demonstrate electron drift over 6 meters**
- **em/hadronic calorimetry**
- **Cross-section measurement**
- **Reconstruction of pion and neutrino interactions**
- **Systematics for far detector**

Where protoDUNE-DPLArTPC is



Detector - Cryostat system



Cryostat

Charge Readout Plane

Field Cage

Cathode & High Voltage

Ground grid

Photon detection system

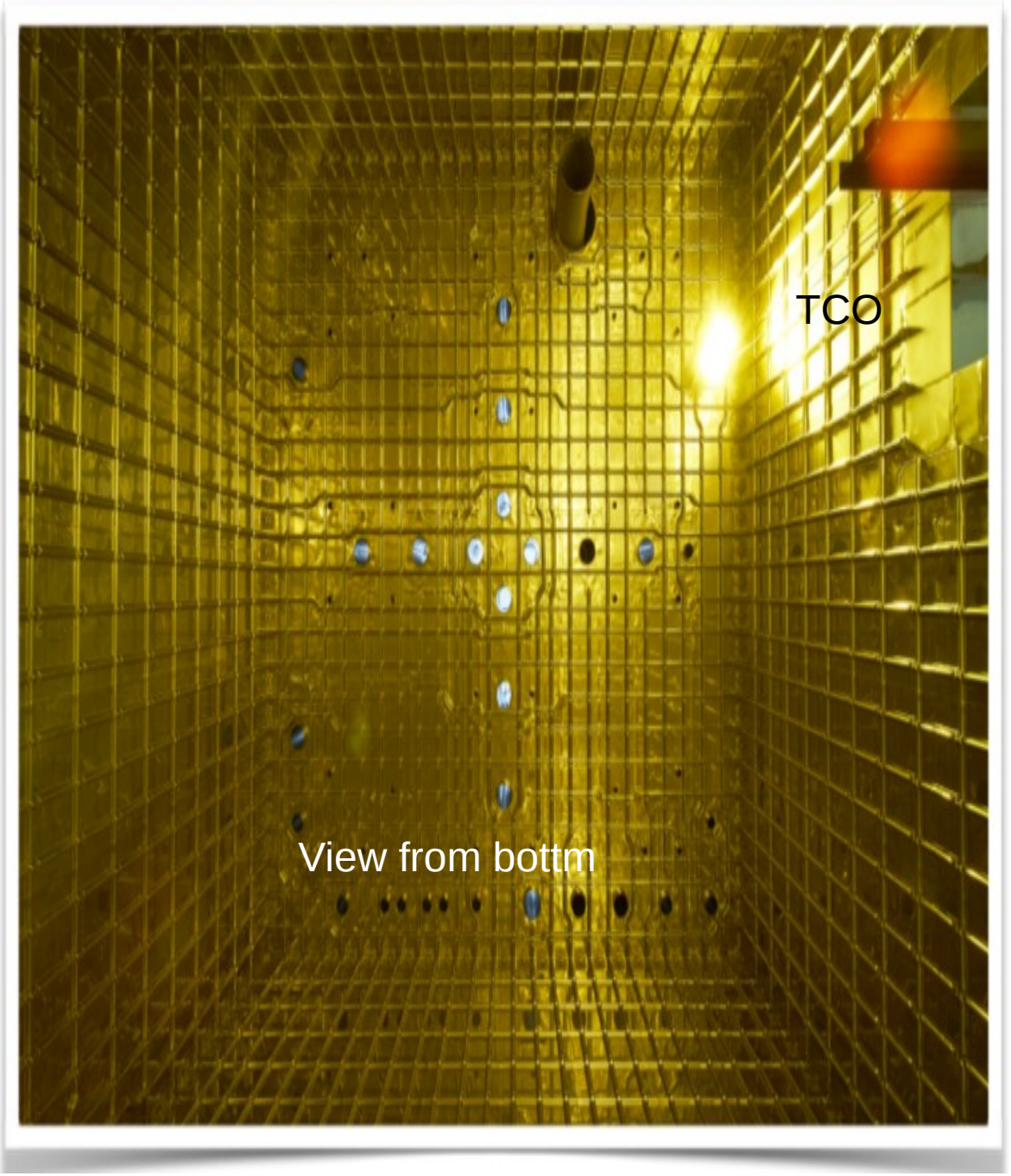
Cryostat

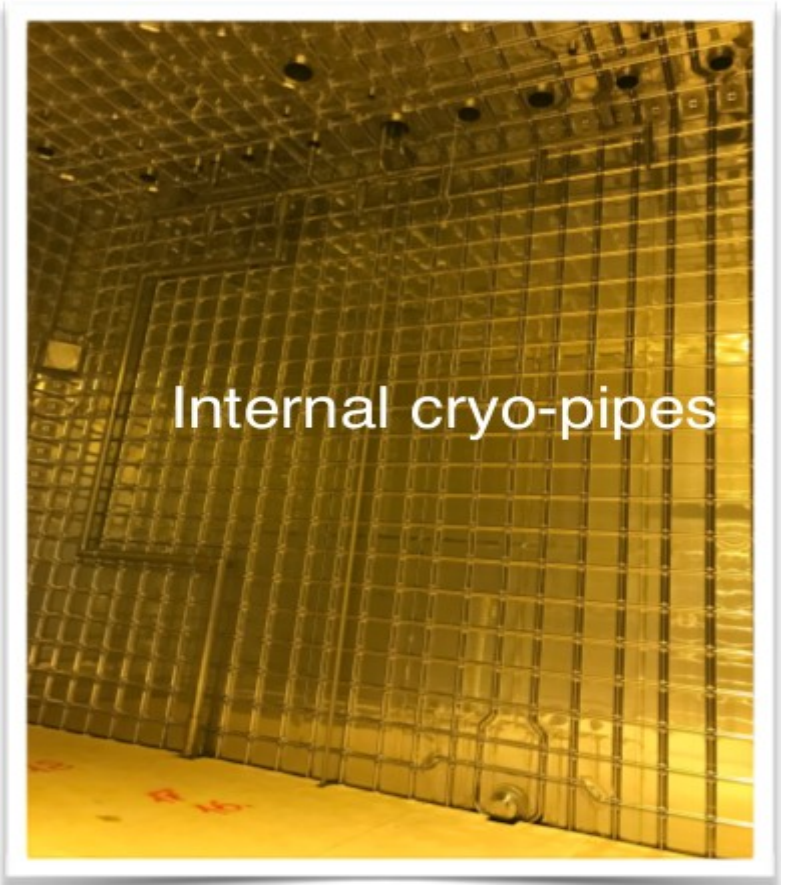
- The cryostat itself is an important part of the R&D
- The cryostat consists of a steel warm outer structure
- Layers of insulation and an inner cold membrane
- Corrugated membrane steel panels used
- Dimension : 10.8m x 11.4m x 11m

Insulation

- passive insulation <1 meter thick made from blocks of Polyurethane+plywood
- designed for 5 W/m^2 heat input
- inner surface made from corrugated "membrane"steel panels welded together

Status :Cryostat

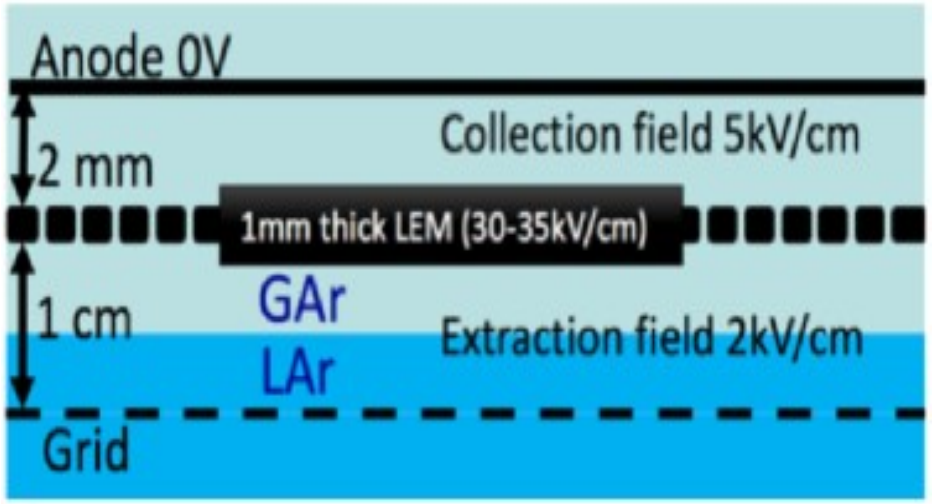


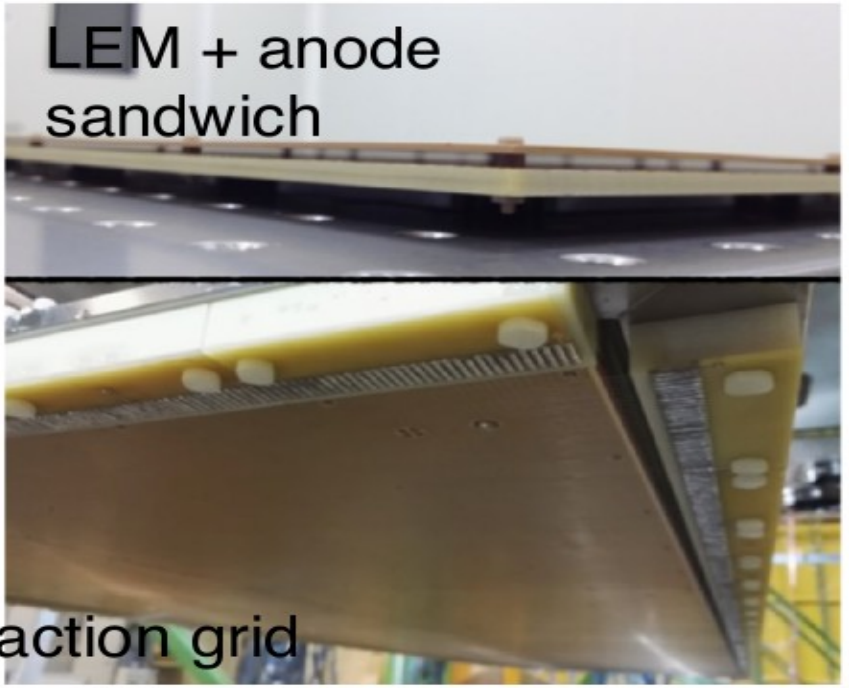


- Cryostat fully installed and leak tested
- Next step: closing of the TCO once the detector is completed
- Internal cryogenics, including all feedthroughs fully installed and leak tested

Dual Phase LAr TPC Charge Readout Plane(CRP)

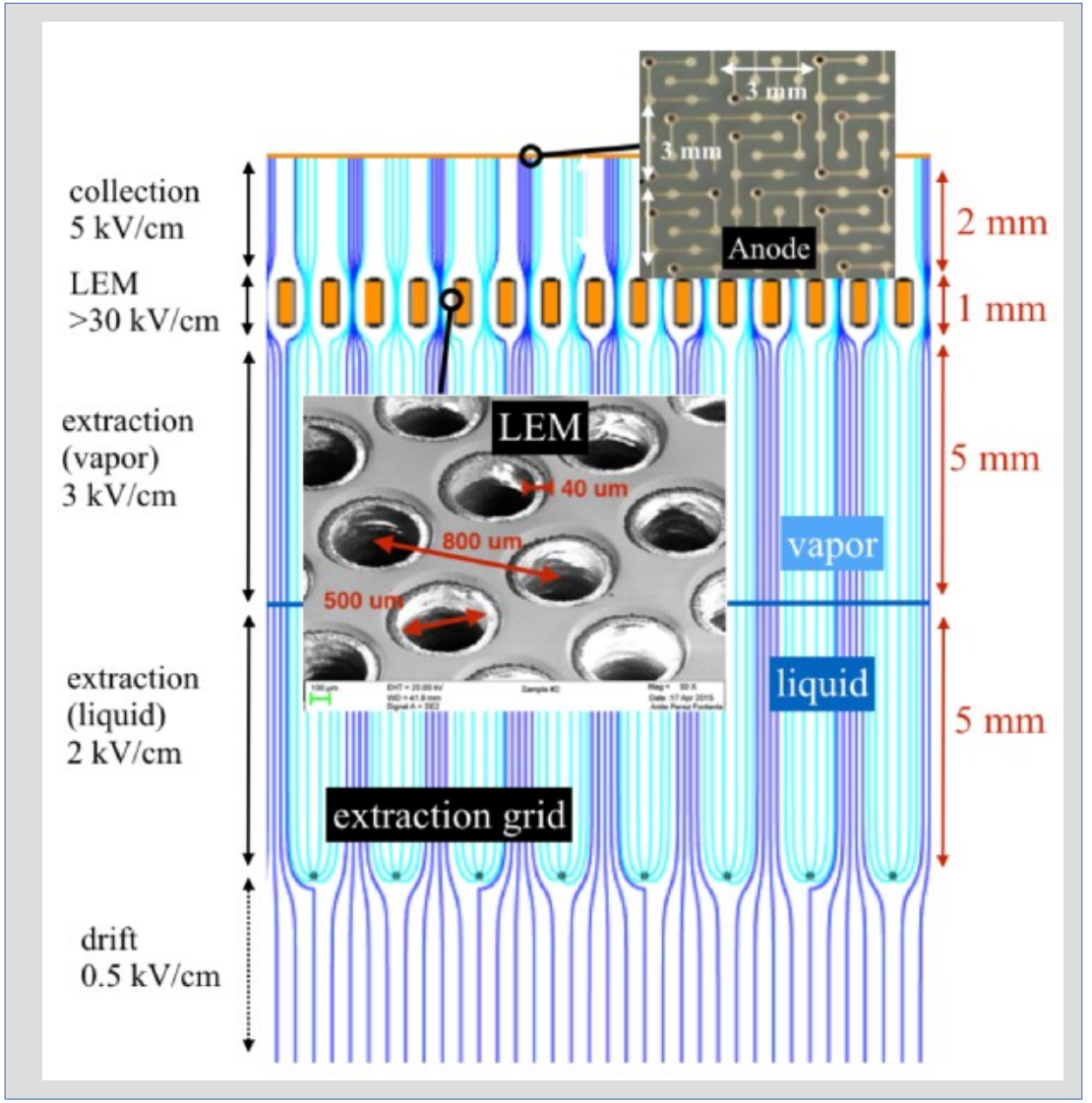
- The grid that provides the charge extraction from liquid to gas, the LEM amplification devices and the anodes are all mounted on a specifically designed frame called **Charge Readout Plane (CRP)**.
- The CRP is designed to precisely maintain the interstage distances between the grid, LEM and anodes at warm and cold.
- The CRP is modular and independent from the drift cage, it can be remotely adjusted to the liquid argon level in order to align the LEMs and extraction grid with the LAr level





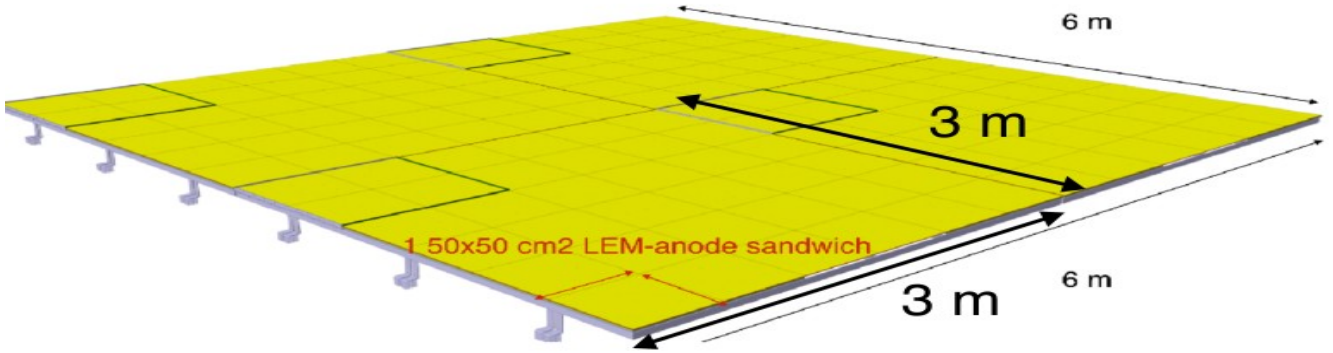
How CRP works ?

- drifting charges are extracted from the liquid to the vapour phase by an electric field in the liquid of around 2 kV/cm
- the charges once in pure argon vapour are multiplied inside LEMs (Large Electron Multipliers)
- the amplified charges are collected on a 2D segmented anode

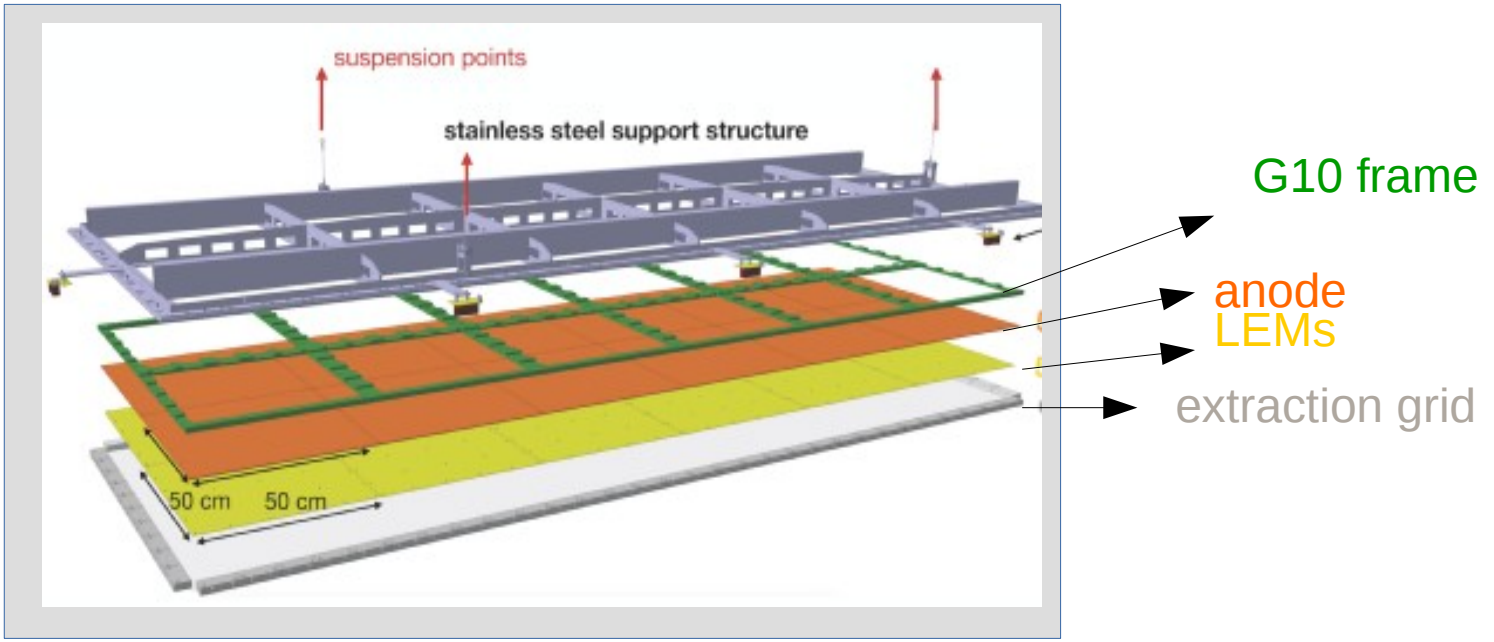


CRP design

- protoDUNE-DP and DUNE-10kt: each CRP functions an independent detector of 3x3 m^2 unit

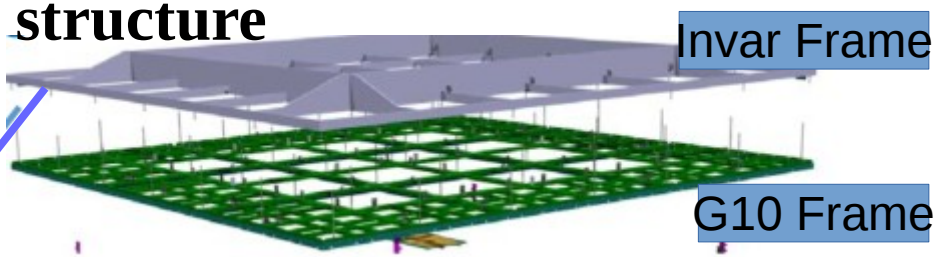


Four 3x3 m2 CRPs for protoDUNE-DP



CRP construction status

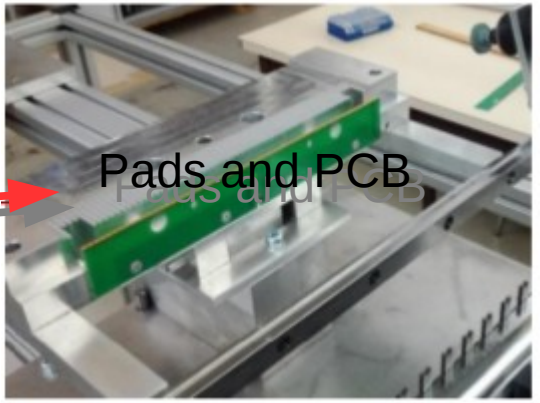
CRP Invar Frame for mechanical structure



4 CRP Invar frames + 1 mock-up for load test delivered on March at CERN

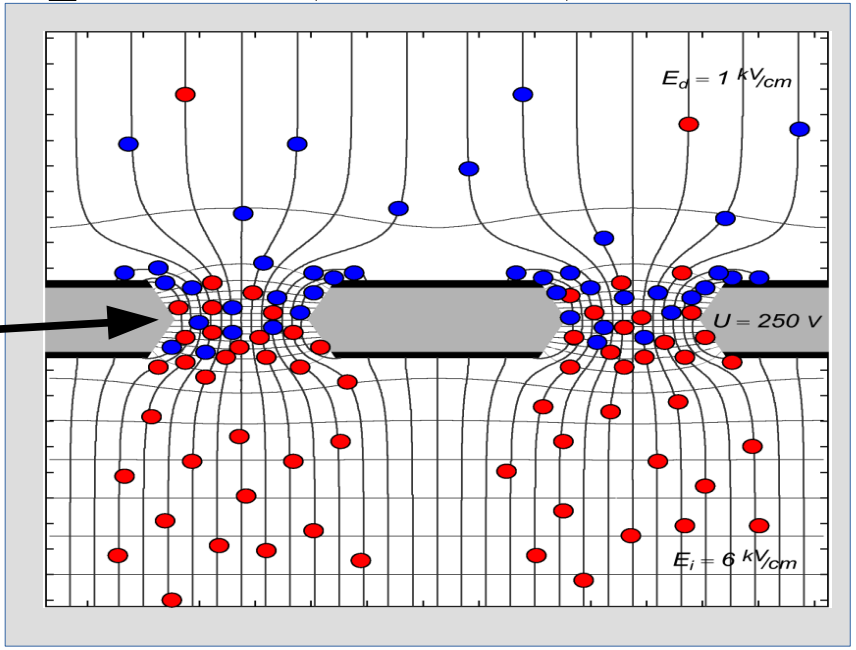
Extraction Grid

- 100 μm diameter stainless steel wires
- Wire pitch 3.12 mm, matches with anode pitch
- Wires soldered in groups of 32 on a pair of independent tensing pads
- PCB are connected with the pads



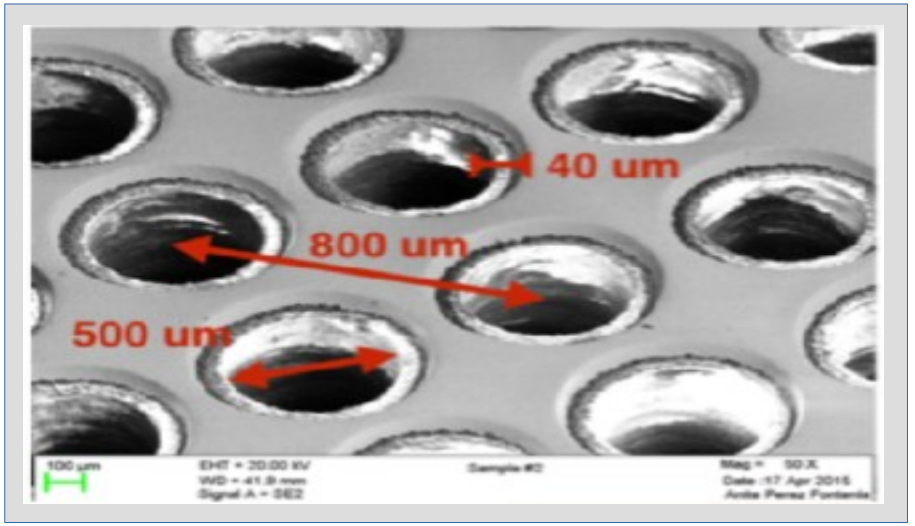
Large Electron Multiplier (LEM)

- Concept of Large Electron Multiplier (LEM) is same as Gas Electron Multiplier (GEM)
- The general technique of electron multiplication via avalanches in small holes



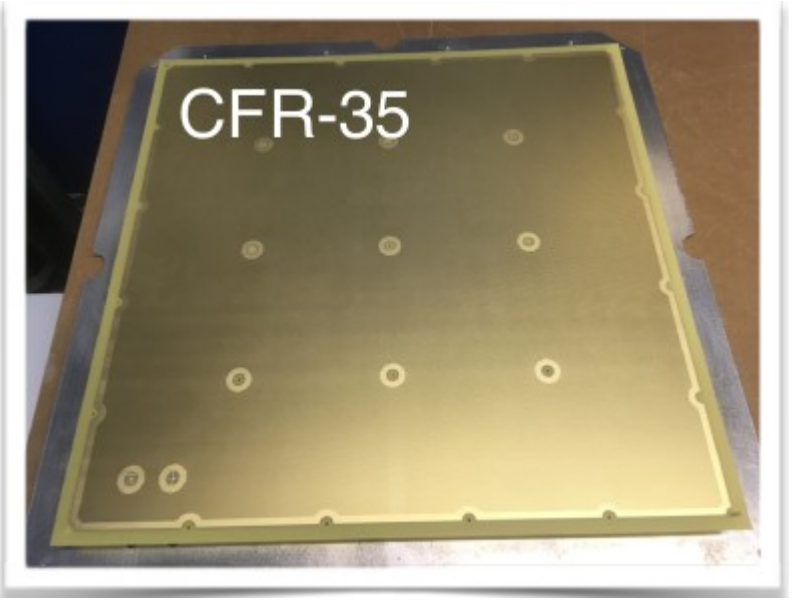
The use of the LEM is motivated by the following facts:

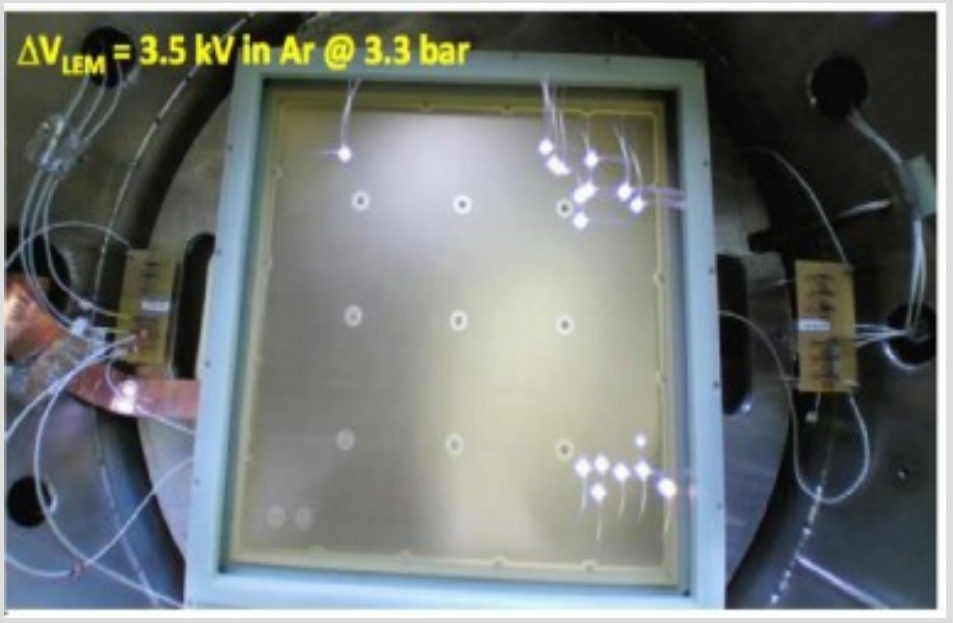
- ✔ **a wide range of gain is achievable (10 to 10^3)**
- ✔ **the gain is easily adjustable to a large spectrum of physics requirements**
- ✔ **large surfaces can be covered as a collection of individual**
- ✔ **LEMs can be operated in pure Ar gas, as required in double-phase operation**



LEM-DP

- **LEMs are built from 1 mm thick 50×50 cm^2 standard PCB epoxy plates**
- **Holes of 500 µm diameter are mechanically drilled in a honeycomb pattern with a pitch of 800 µm**
- **Each CRP consist of 36 LEMs**

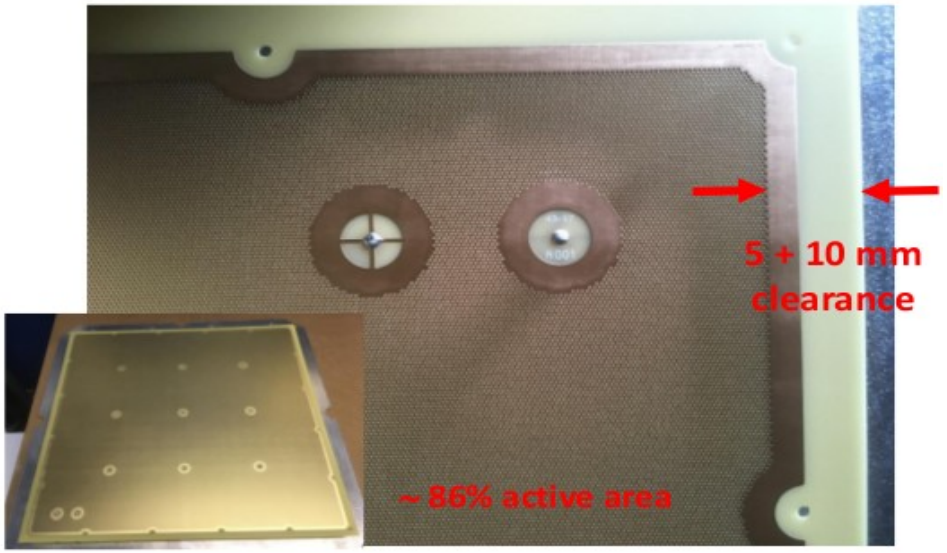




- **Studies performed pure GAr at room temperature and 3.3 bar**
- **3 different types of LEMs (CFR-34, CFR-35, CFR-36) tested**

LEM: Development

CFR-35 – NP02



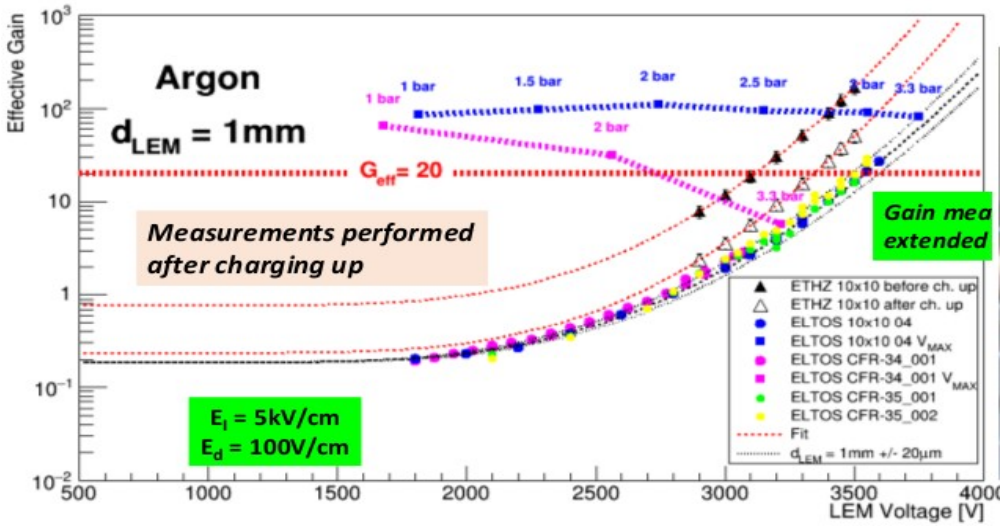
Before Charging up
@ 3.5 kV

- ***G >100 in DLAr***
- ***No trip for >40h***
- ***Spark rate : ~3/h***

@3.1kV

- ***G >20 in DLAr***
- ***No trip for >64h***
- ***Sparks: 0***

LEM CFR-35 Test in Ar @ 3.3 bar

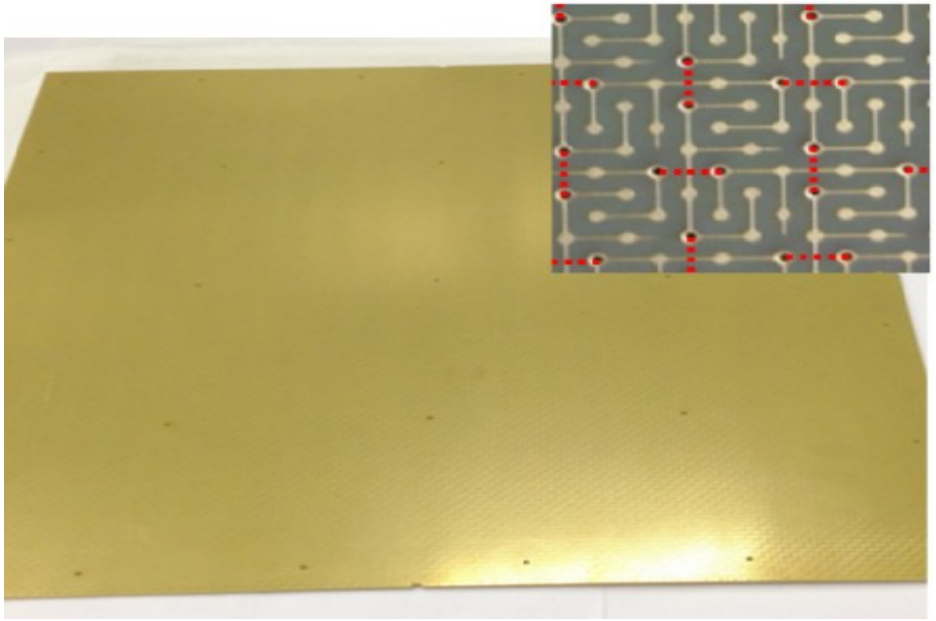


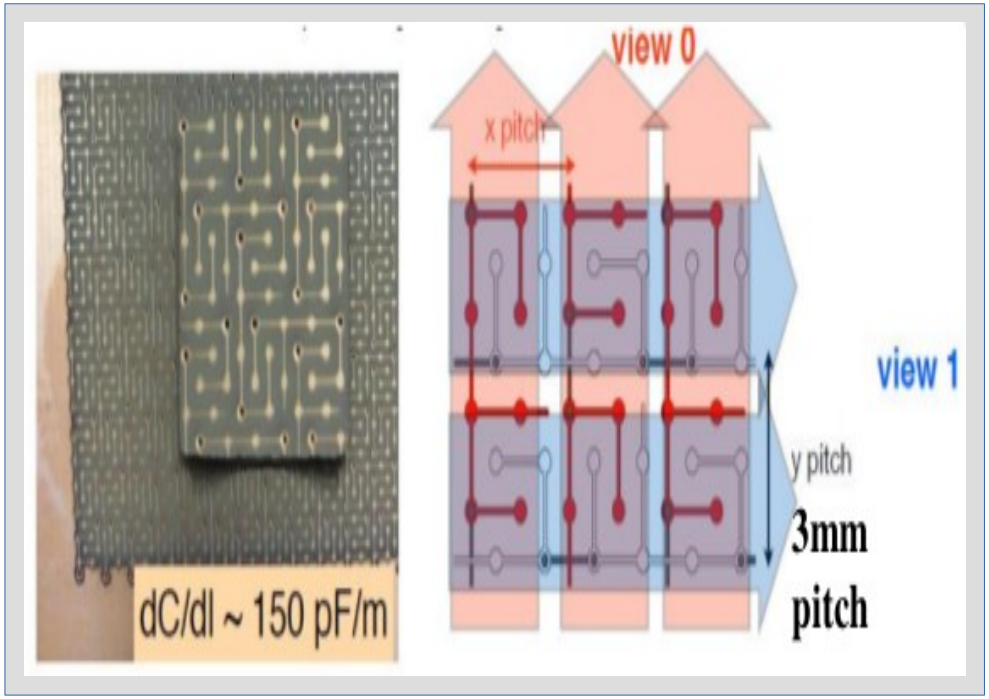
LEM : Production

- Initially, same design as 311 prototype (CFR-34) for first 2 CRPs.
- Production for 1 CRP ended in Nov. 2017. Tests performed @ CEA/Irfu showed maximum HV operation @ 32kV/cm, confirmed by 3x1x1
- LEM production for 2 CRPs restarted in Dec. 2017 with new design.
- 28/36 LEMs for CRP1 validated so far. Expect CRP1 completed in 2-3 weeks
- LEM production for CRP2 started. Should be completed by end of June

Anode-DP

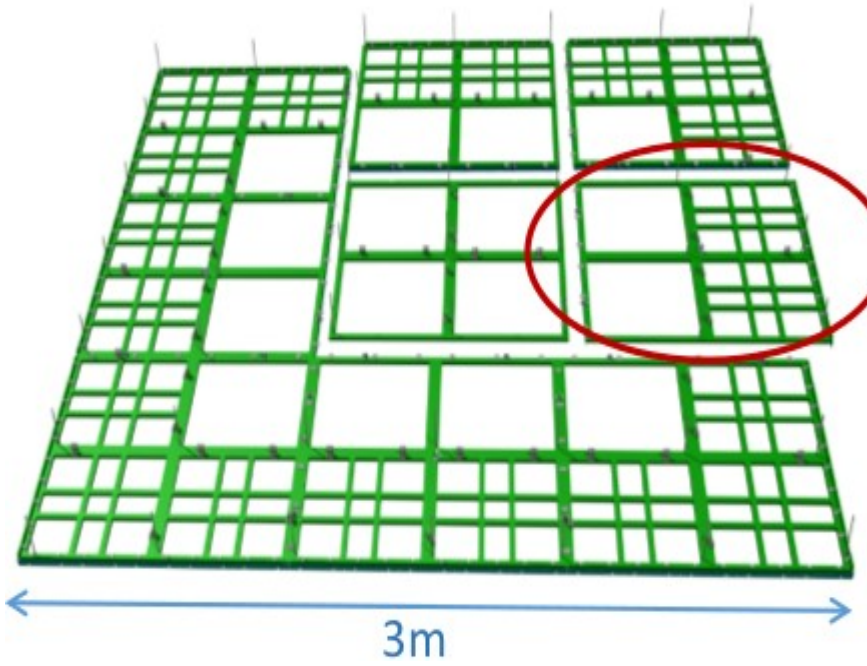
- The anode is a four-layer PCB having a set of orthogonal strips with a 3.12 mm pitch that provide the two views of the event
- Printed circuit anode with a 2D structure providing two collection views. No need for the induction plane
- The pattern was optimized to ensure 50:50 charge sharing between both views and best resolution on energy loss/unit length

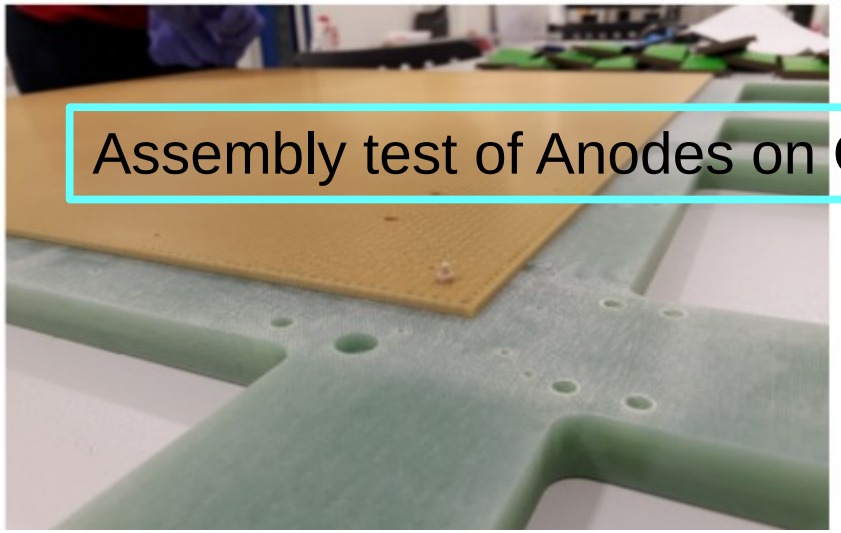




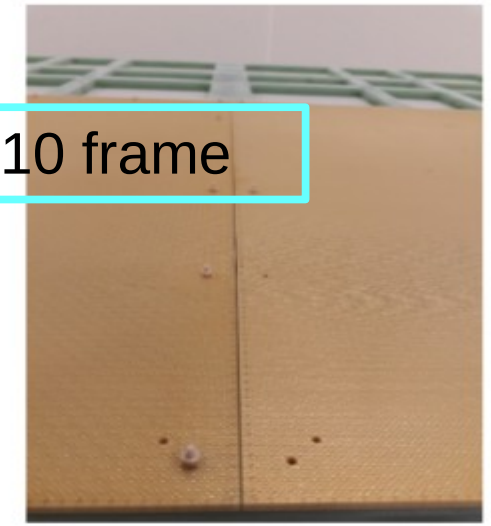
G10 frame and Anode: Status

40 anodes for first CRP produced and received at CERN





Assembly test of Anodes on G10 frame

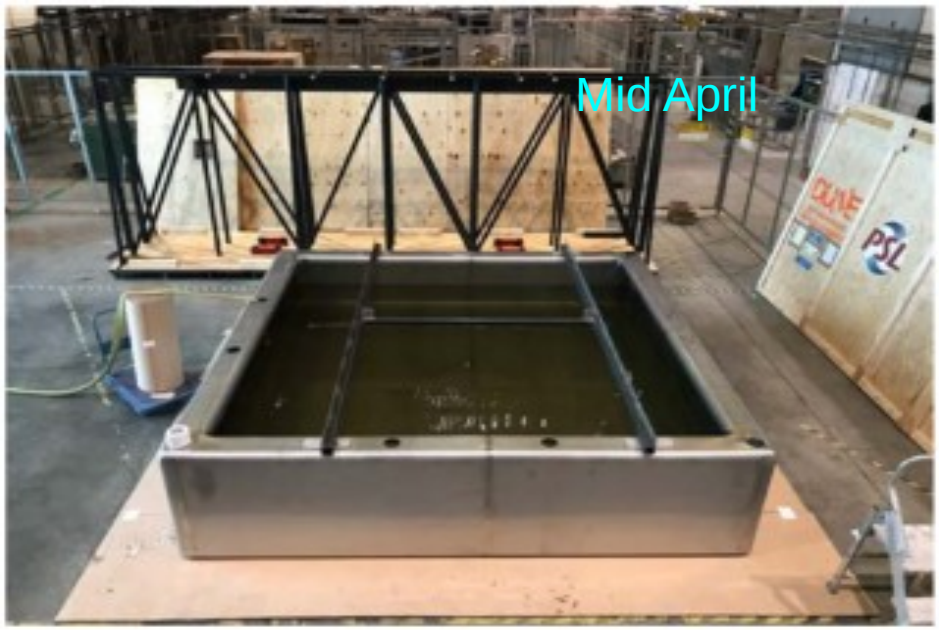


Full G10 frames batches delivery expected soon

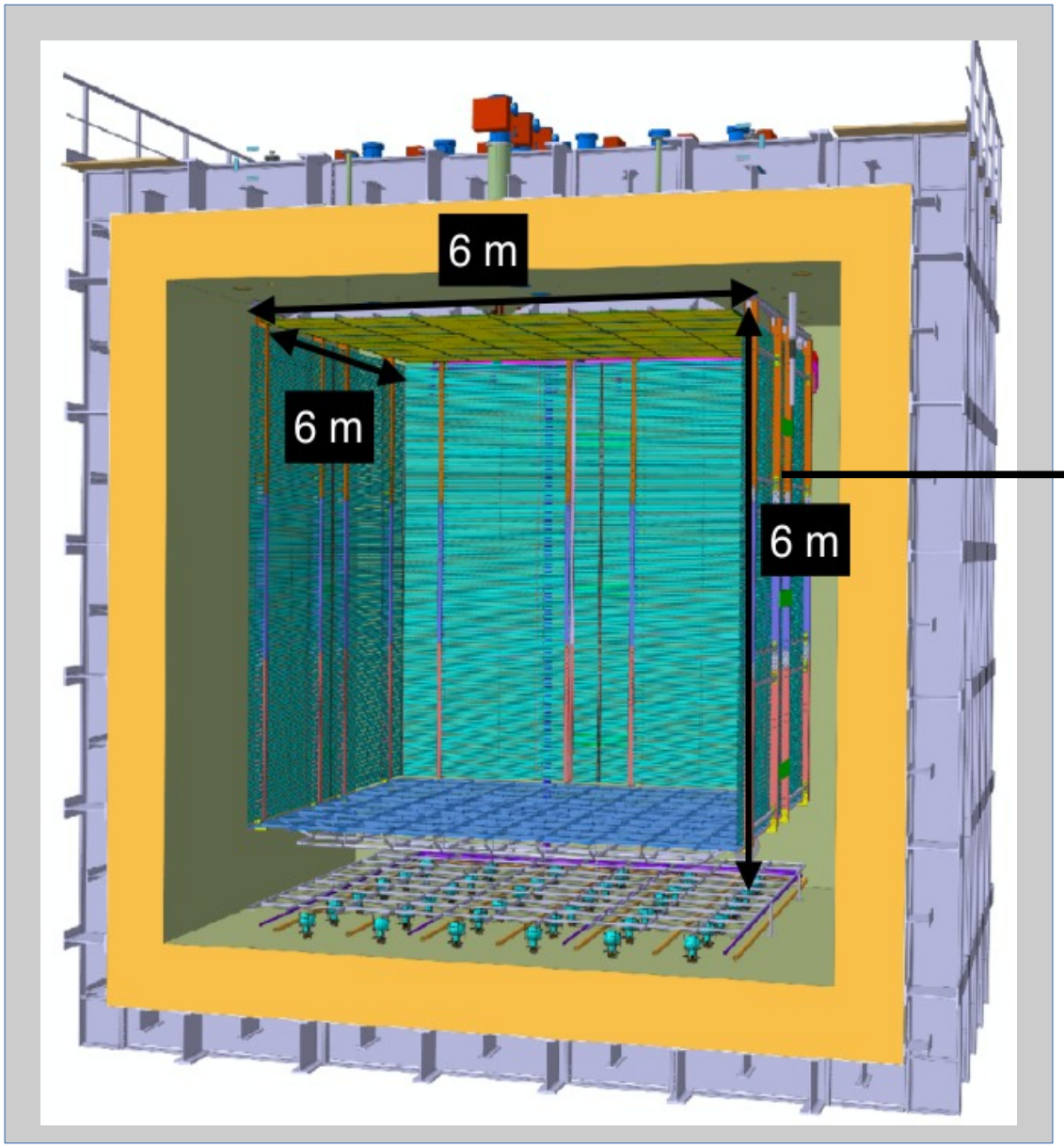
CRP testing (cold box)

- Electrical and mechanical tests of each final CRP in nominal thermodynamic conditions:
  - Characterization of the operation voltage of each LEM
  - Characterization of the operation voltage of the extraction grid
  - Test the HV contacts and connections (LEM & grid)

- Cold Box:
  - Mechanical construction of the cold box completed
  - The cold box was transported and installed in its final position
  - Cold membrane welded and leak tested



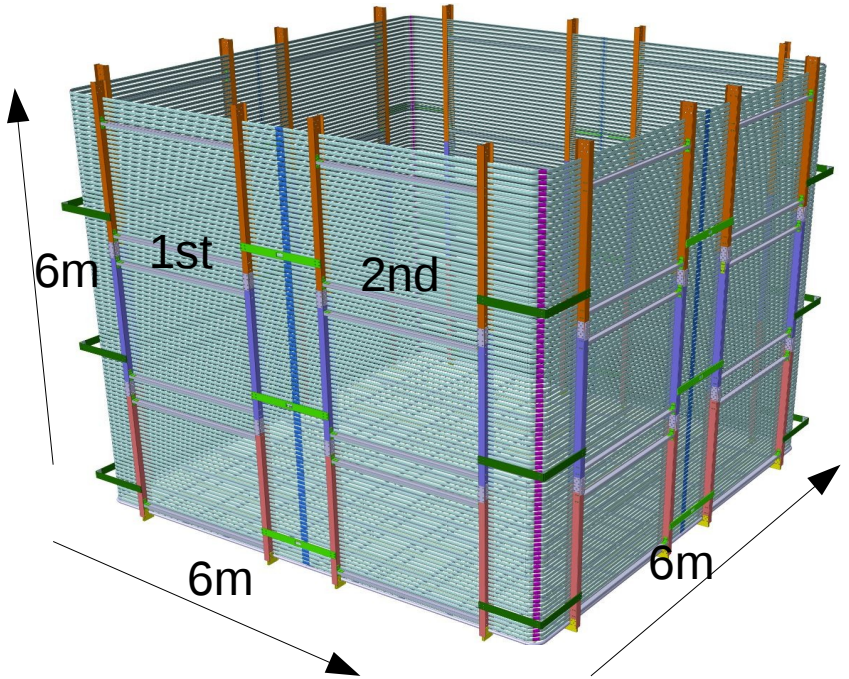
Field Cage



Field Cage

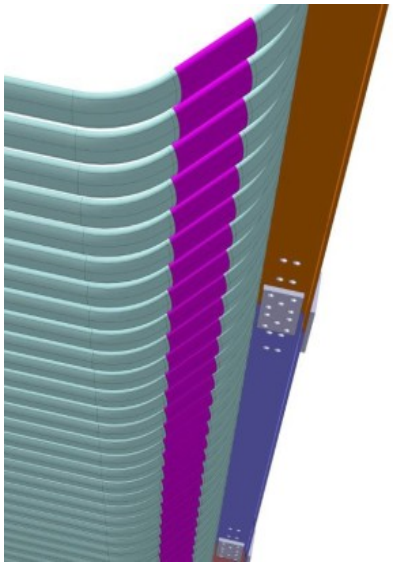
- **Field cage provides uniform electric field (500 V/cm) across the entire drift region**

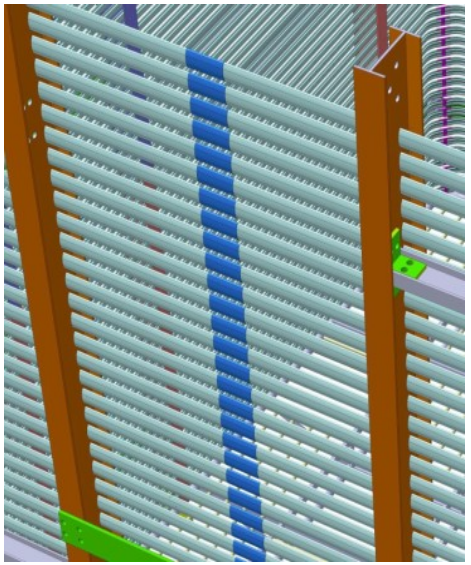
We (UTA &ETHZ) are in charge of design, production, testing and installation of the Field cage for protoDUNE Dual Phase detector

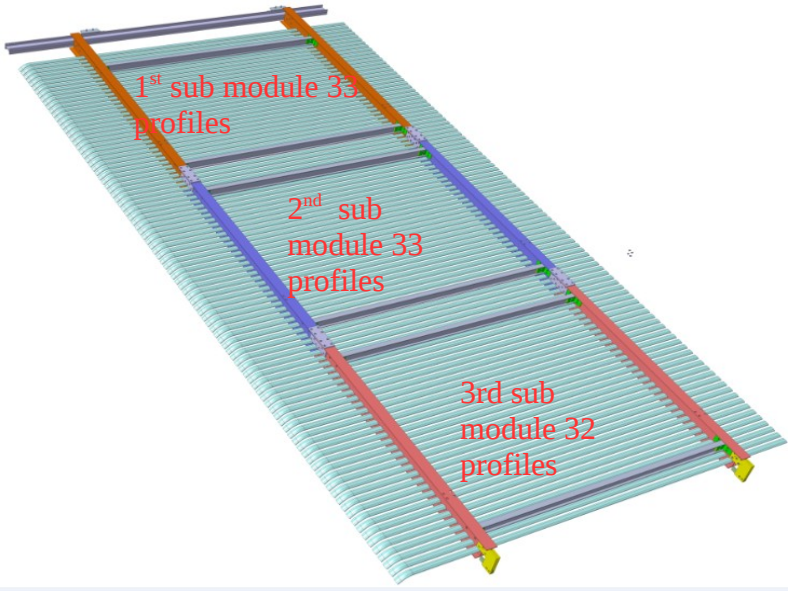


Field Cage : Design

- Consists of 8 vertical modules of 6310 x 3010 mm^2 (2 modules per detector face)
- Each module is assembled out of 3 distinct sub-modules
- Three distinct types of sub-modules with 33, 33, and 32 profiles each held by a frame with two 6” and two 3” horizontal FRP I-beams
- 98 electrically continuous rings in 60mm pitch using straight aluminum clips
- Each profile is made of extruded aluminum with a supporting rib running in the middle
- 11 profiles with one end bent at 45 degrees are electrically connected by 2 divider boards
- Inter-module connections made with FRP plates connected with FRP threaded rods

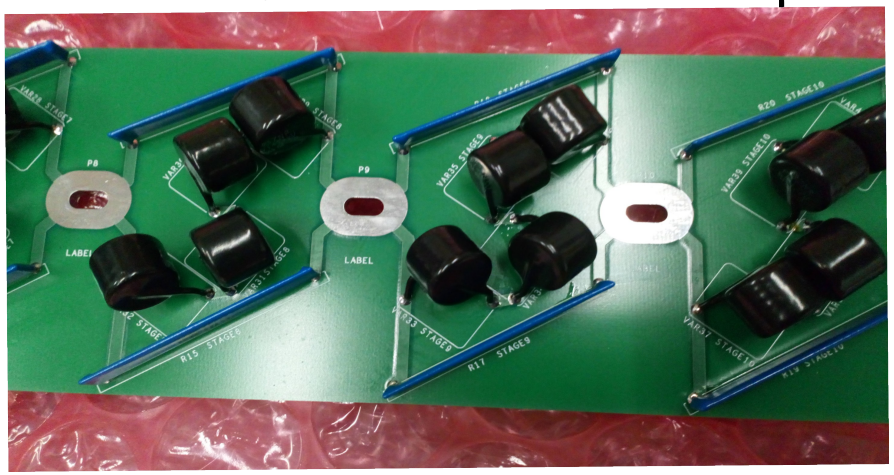


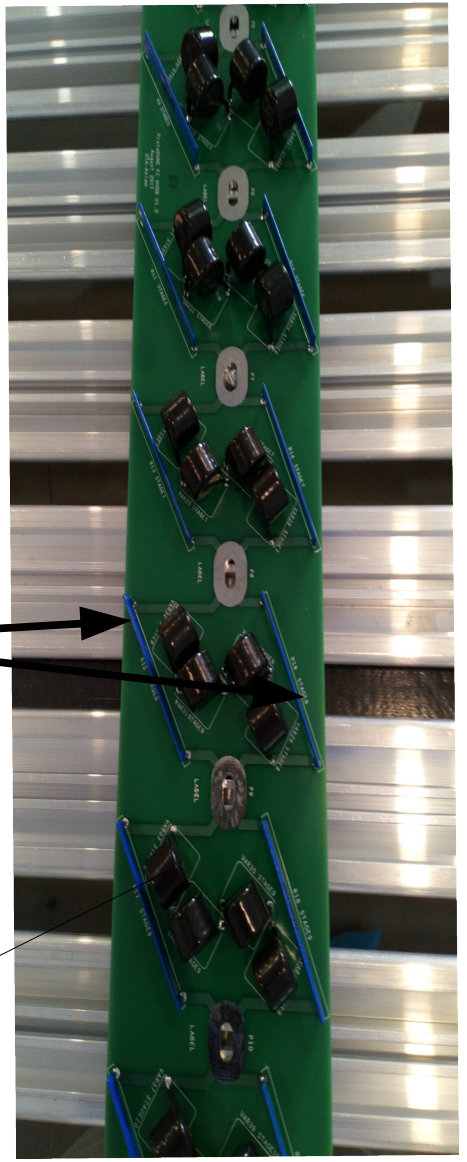




Voltage divider PCB for Field cage

- Designed custom made High Voltage divider board to generate uniform electric field of 500V/cm to 1kV/cm
- We use the printed circuit board
  - → Easy handling and installation, robust mechanical and electrical connection
  - → perform and survive in LAr for long time
- Two parallel columns of total 20 PCB board will cover the entire field cage
- Each divider chain has two 2GΩ resistors in parallel for each stage for each board, total 0.5 GΩ between two profiles

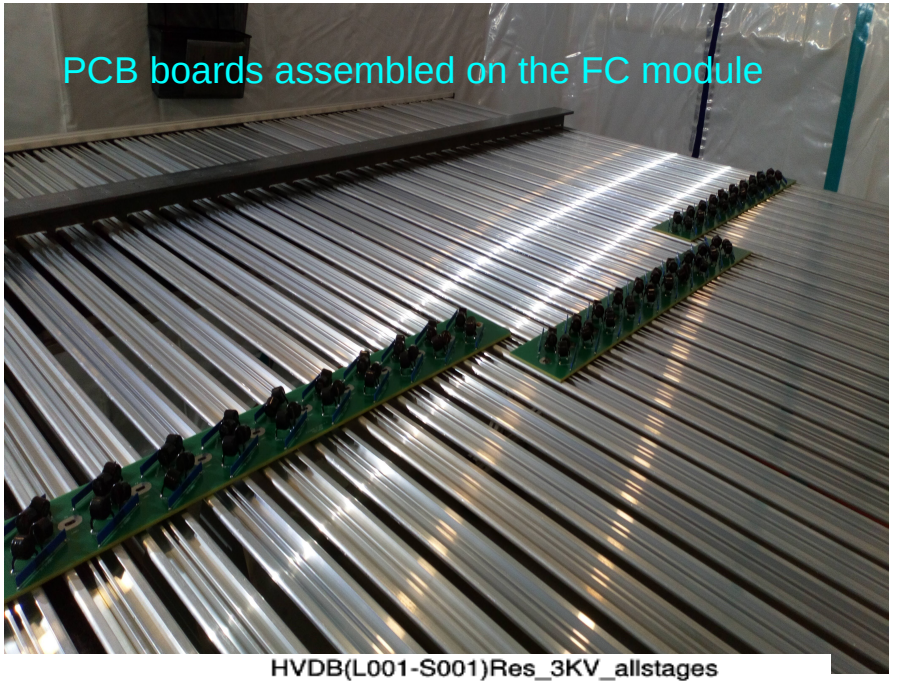


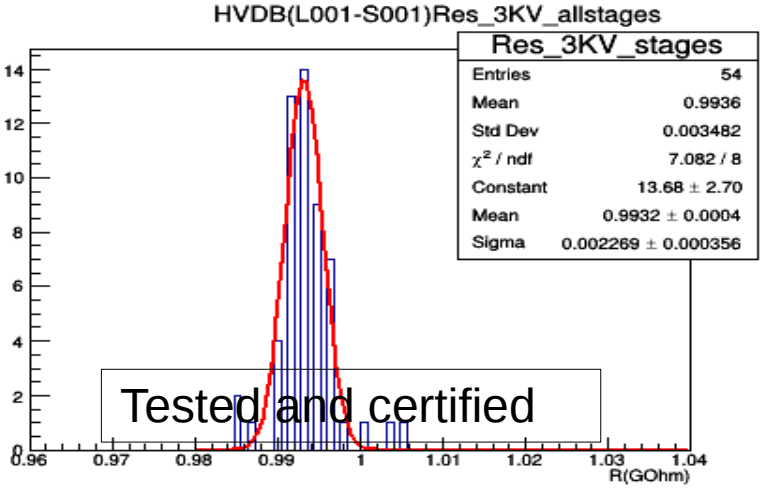


4 varistors in series in each stage(concept first used in MicroBooNE by B.Jones et.al)

Status: Voltage divider PCB

- We have done the calculations and simulation of the current flowing through the entire drift volume of protoDUNE DP and select the proper electrical elements for the divider board
- Designed the PCB board, reviewed and passed **DUNE PRR**
- Developed the procedure for testing the boards in warm and in cold
- All the boards are assembled on the field cage module and tested
- Boards are **tested and certified** (both in warm and in LN_2)and finally shipped to CERN for the installation **in a timely fashion**.

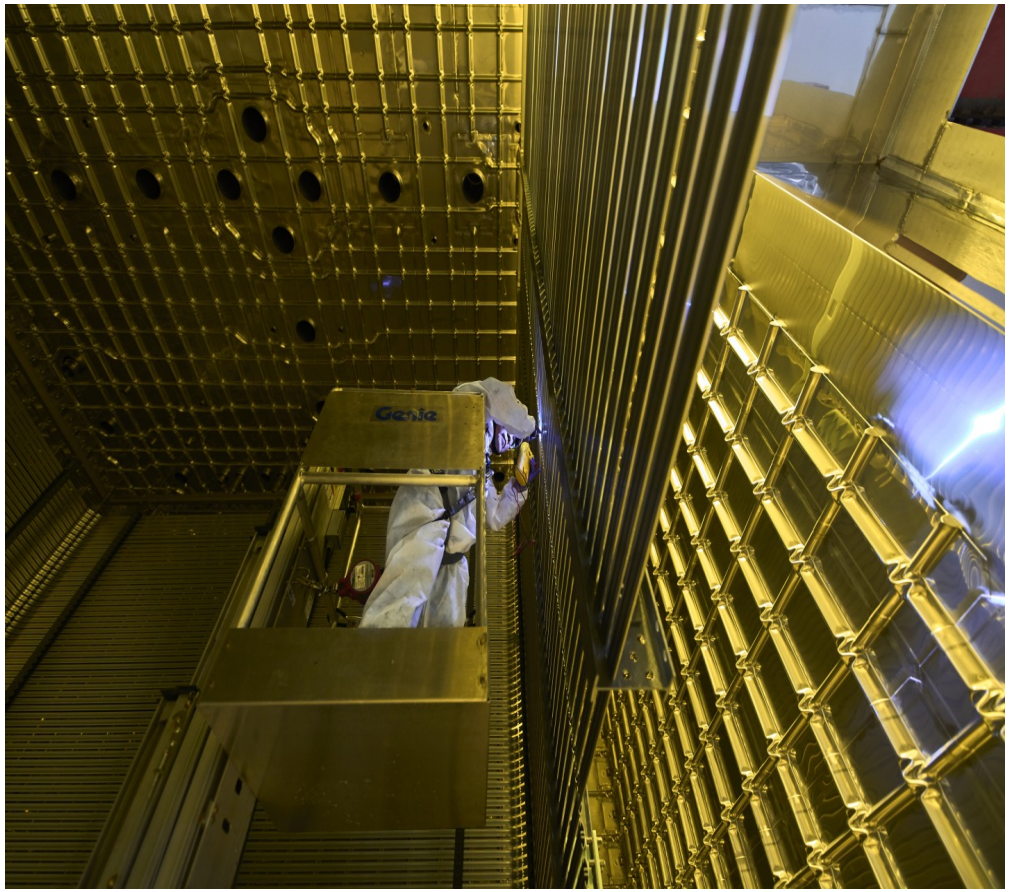




Field cage : Production Status

- We have successfully pre-assembled all (24+3) sub modules at UTA
- The production for 24+3 sub-module parts completed and shipped to CERN
  - Additional spares have been ordered and will be conditioned and preassembled at UTA for shipping if necessary at CERN
- HVDB boards (18+2 long and 2+3 short) have been certified and at CERN
  - Remaining spares have been produced and being tested

Field cage Installation



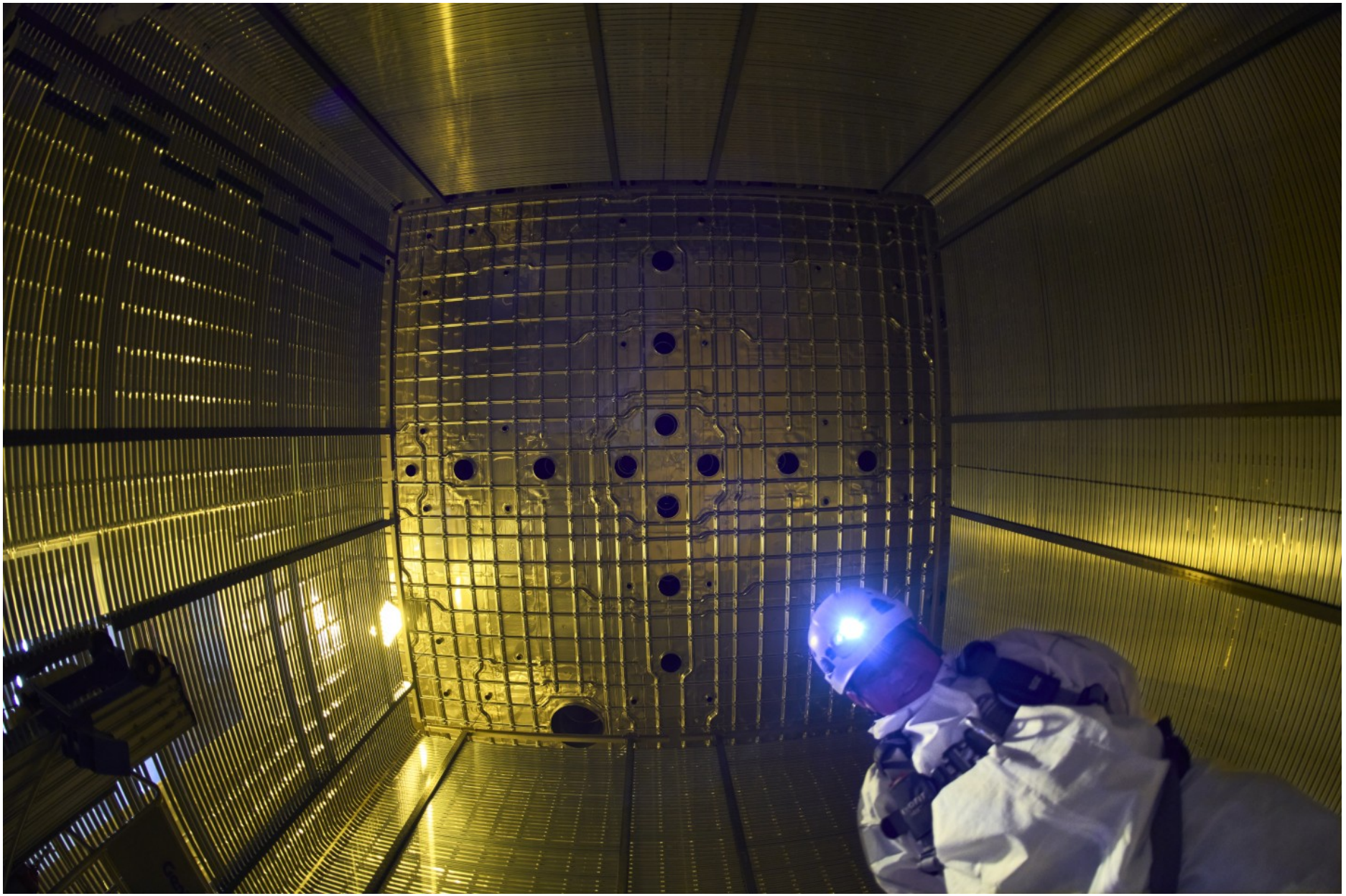
We are the first group to install protoDUNE Dual Phase detector components at CERN

Electrical test of the Field cage

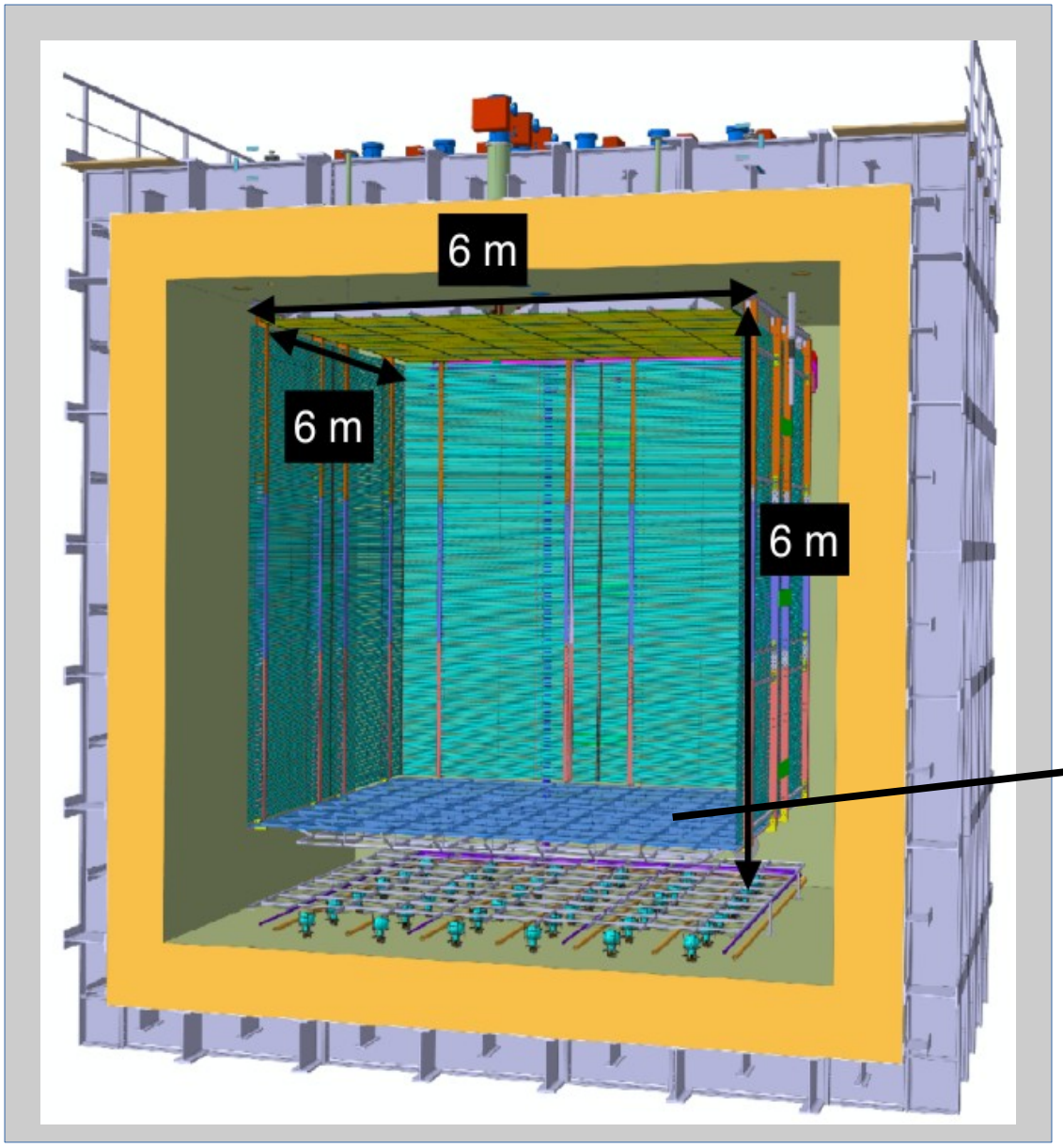
- Voltage applied in the middle of the Field cage
- Ground on top and on bottom of the FC

- **Maximum voltage: -150 kV**
- **Run several hours => no discharge**
- **Current is stable and linear**

FC Installed



Cathode and High Voltage system

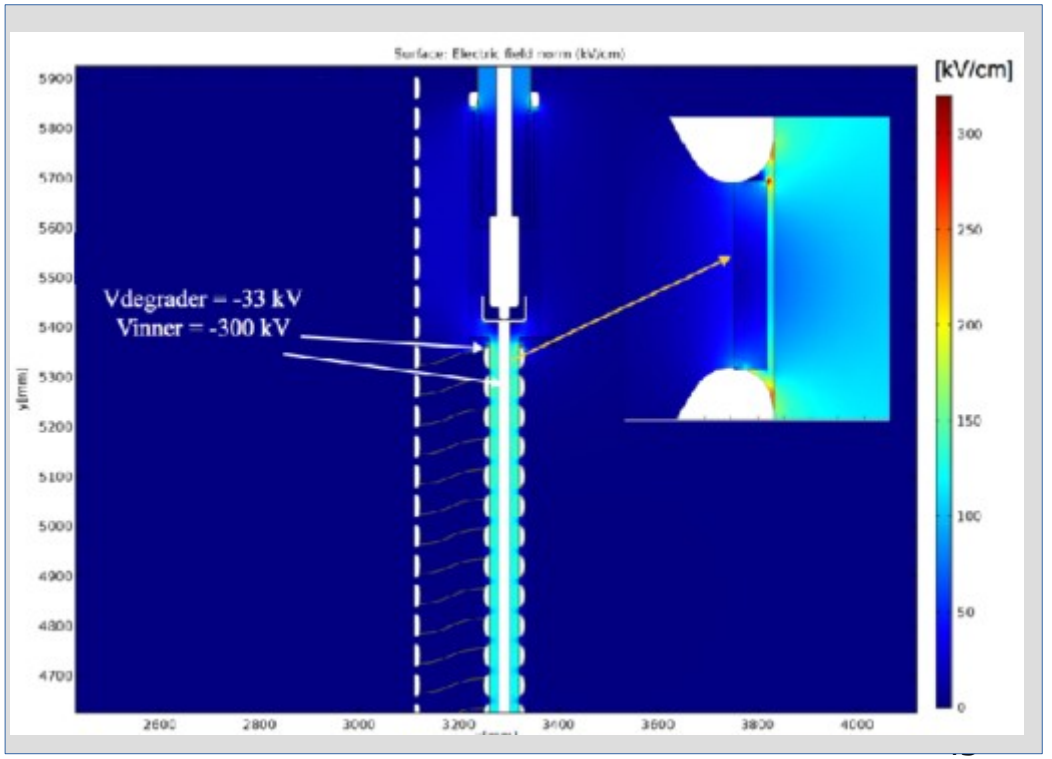


Cathode and High Voltage system

- Power supply :

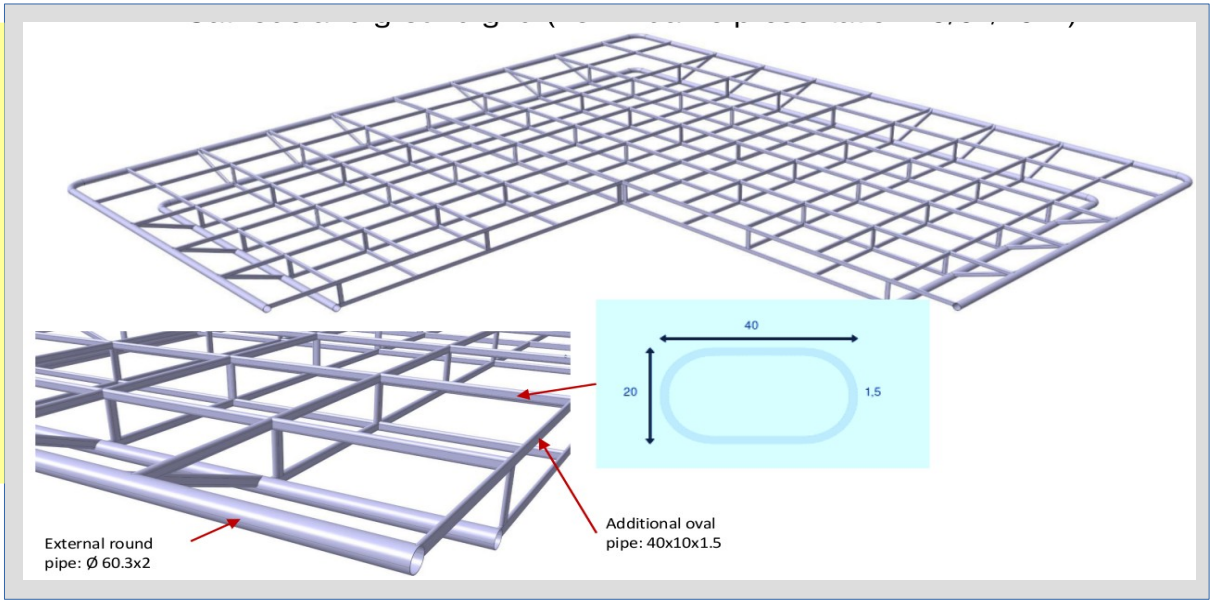
  - One Heinzinger neg High Precision High Voltage Power Supply (-300kV)

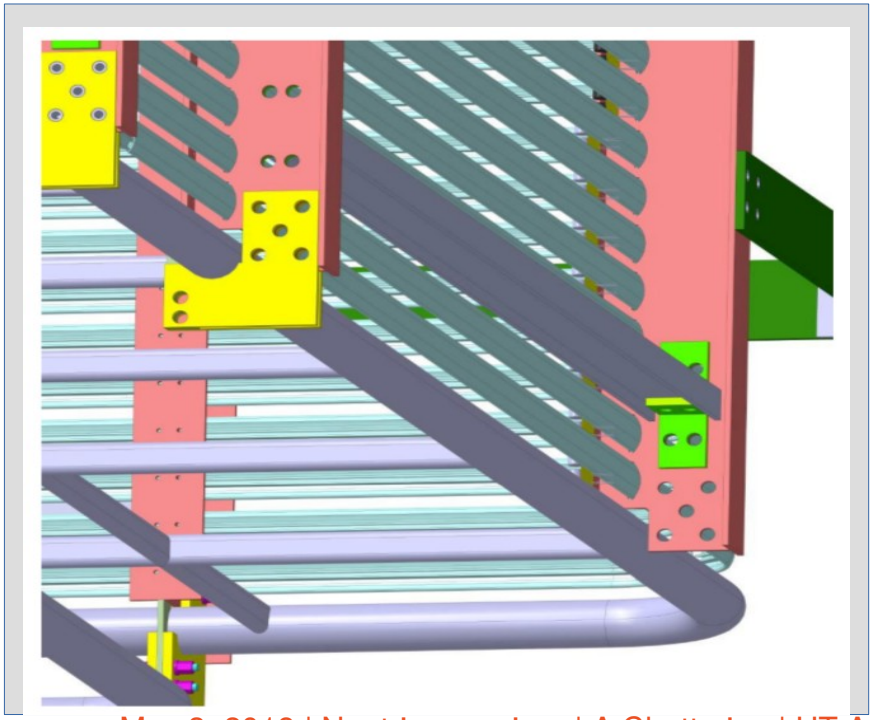
  - Upgrade of the Control Unit for the previous Heinzinger recently shipped to CERN

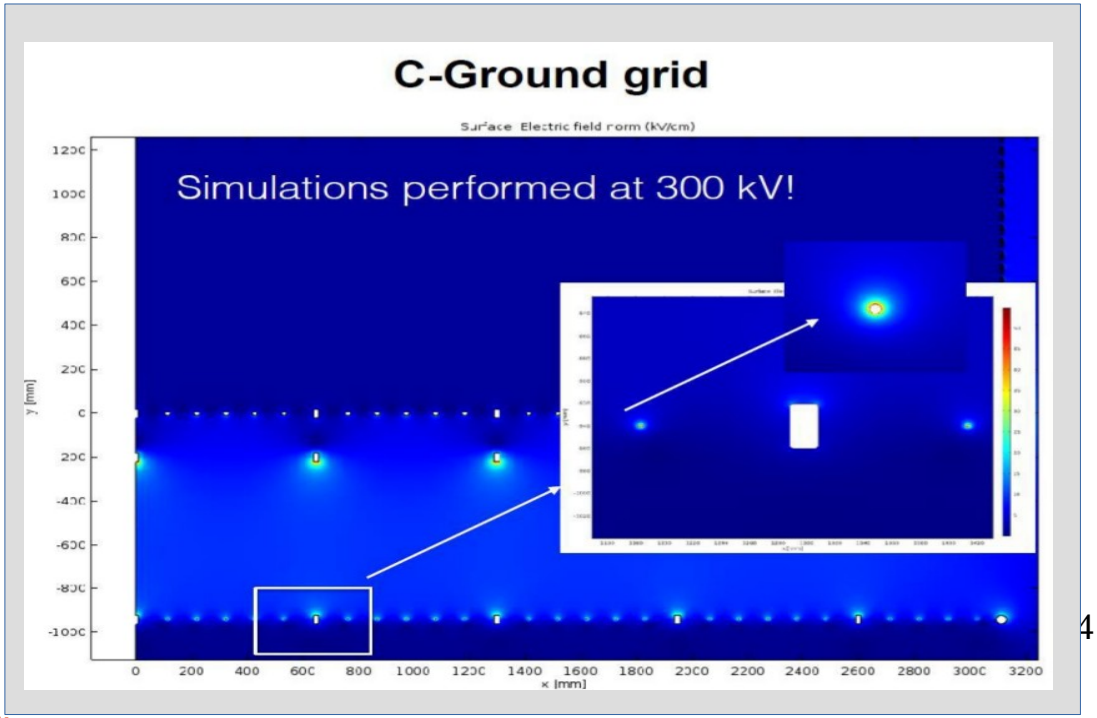


Cathode

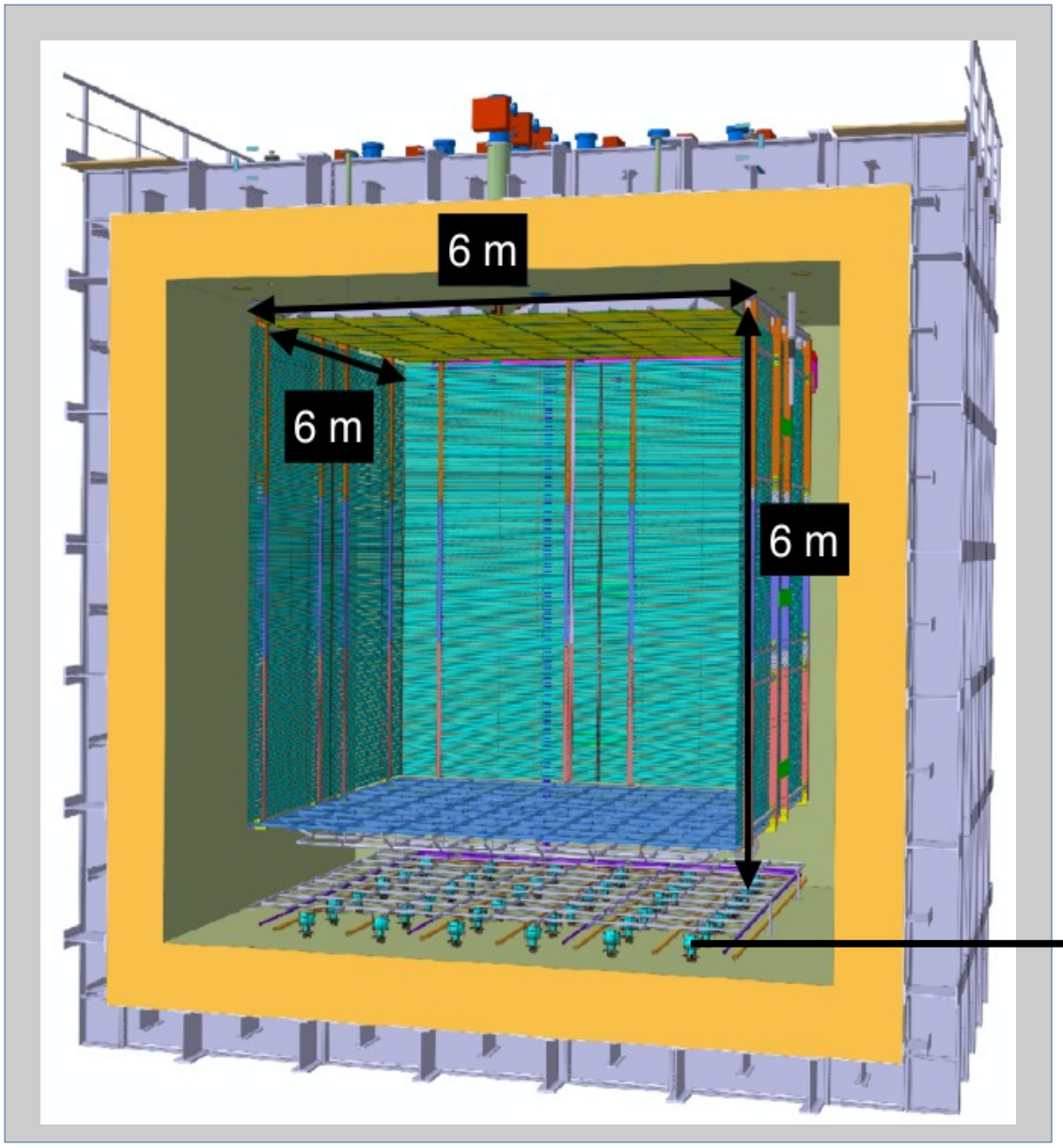
- 4 modules to be assembled in the cryostat
- Engineering work completed
- Procurement of the raw material and construction at CERN







Detector Cryostat system

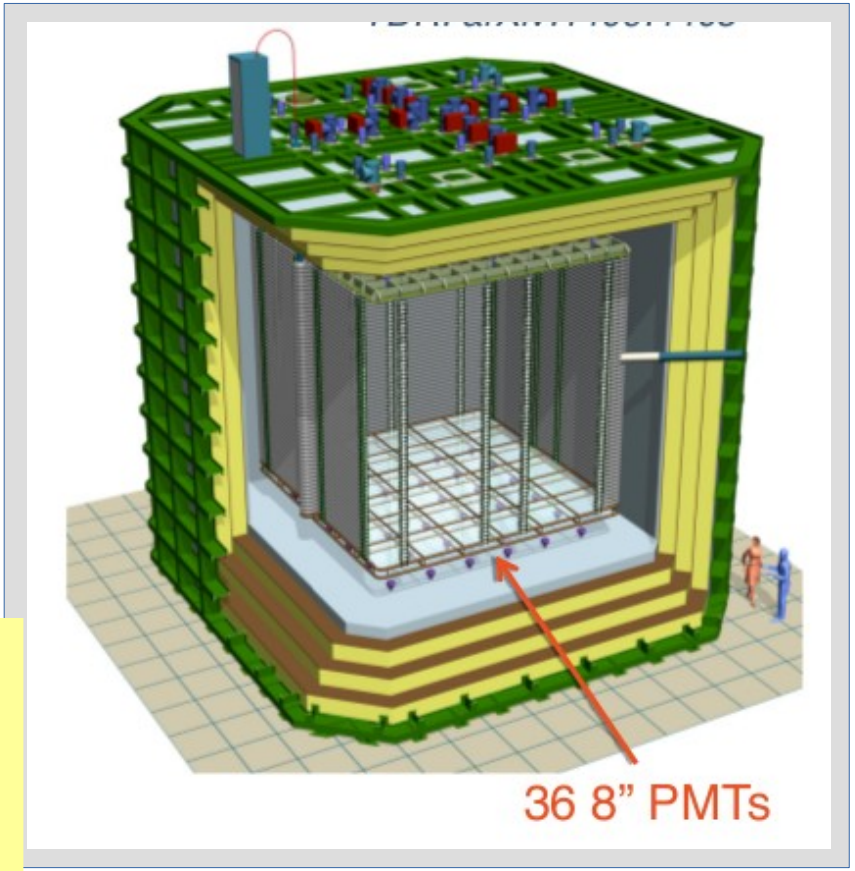


Photon detection system

Photon Detection system

- **Basic configuration:**

- 36 8” cryogenic photomultipliers
- Wavelength-shifter: TPB coating on PMT
-Voltage divider base + single HV-signal cable + splitter (external)
- Light calibration system



- **Goals of the light detection system:**

- t_0 for both beam and non-beam events (cosmic background rejection)
- Possibility to perform calorimetric measurements and particle identification

Light system preparation

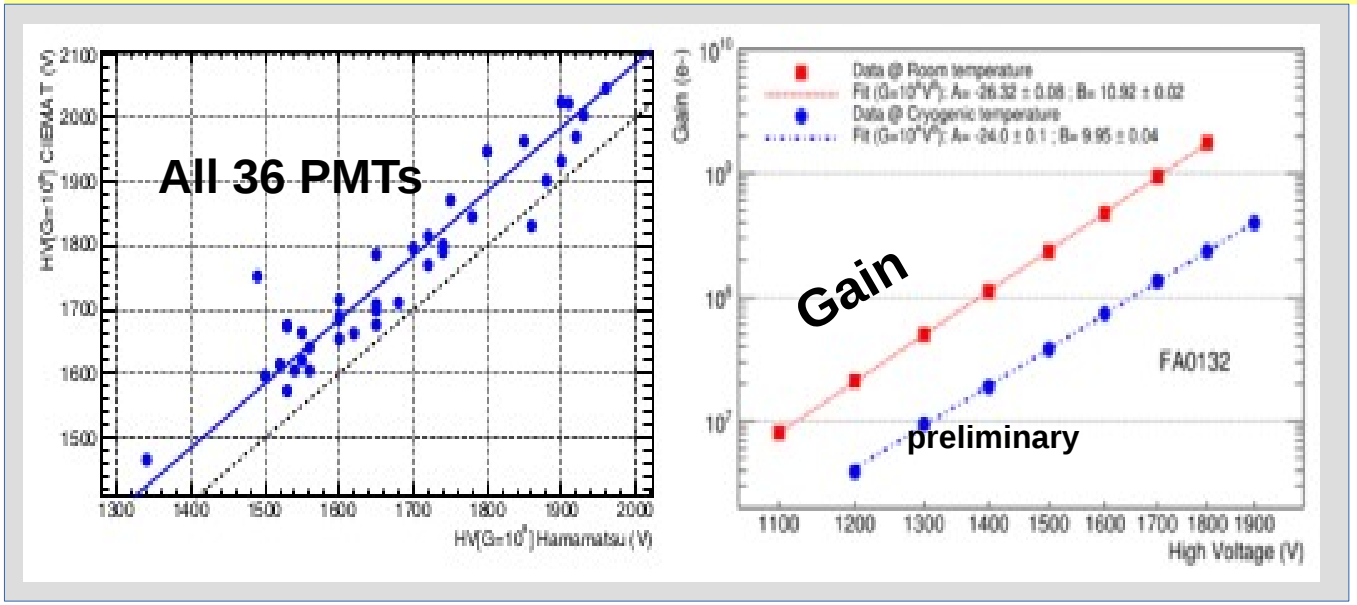
- Full characterization of 36(+4 spares) 8” Hamamatsu PMTs completed at room and cryogenic temperature

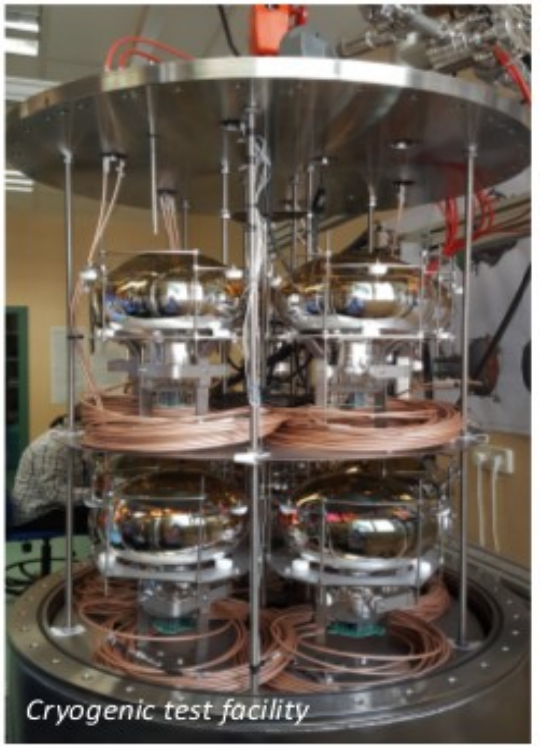
- Dedicated cryogenic test facility used for testing 10 PMTs at once

- Final system (HV divider, mechanical support and 23m cables) assembled and validated in LN_2

- Database ready including: dark current and gain vs HV curves +SPE waveforms for each PMT

- All PMTs are ready for installation and are being prepared to be shipped to CERN





TPB coated PMT

CF40 w/ 3 ft (x2)

Electronics

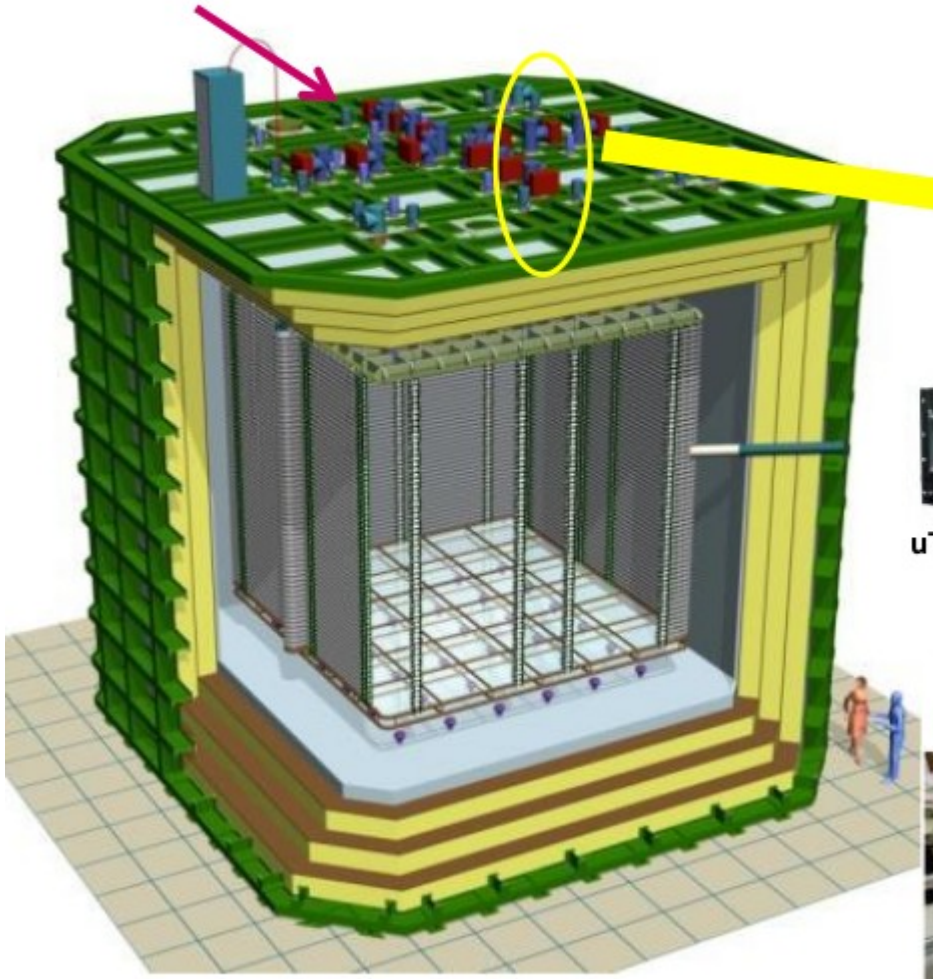
Full accessibility provided by the double-phase charge readout at the top of the detector

- **Digital electronics at warm on the tank deck:**
  - Architecture based on uTCA standard
  - 1 crate/signal chimney, 640 channels/crate

→ 12 uTCA crates, 10 AMC cards/crate, 64 ch/card

- **Cryogenic ASIC amplifiers (CMOS 0.35um) 16ch externally accessible:**
  - Working at 110K at the bottom of the signal chimneys
  - Cards fixed to a plug accessible from outside

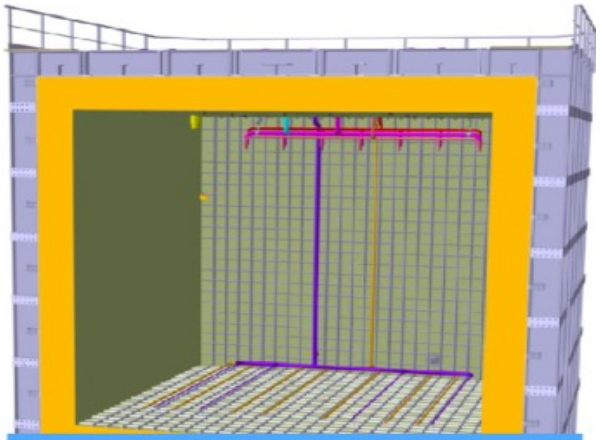
→Short cables capacitance, low noise at low T



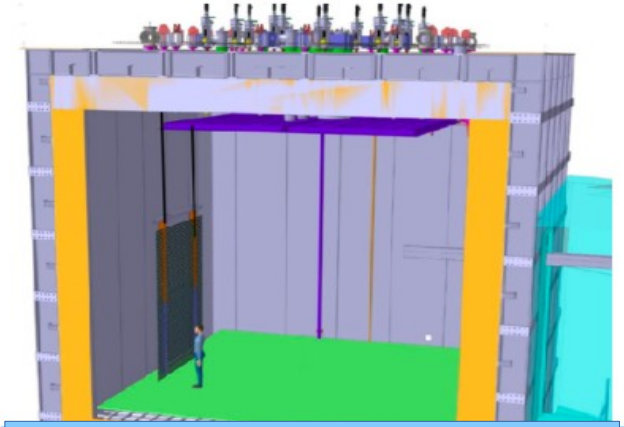
Signal chimney

uTCA crate

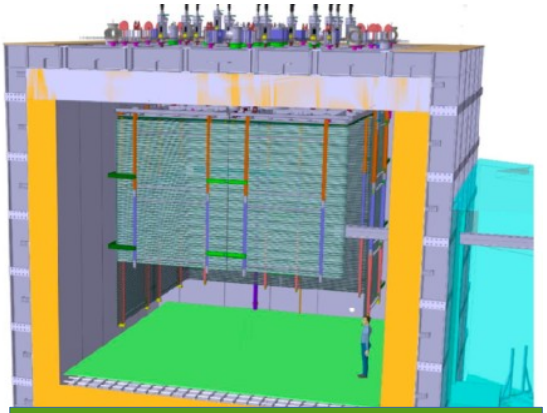
protoDUNE-DP installation sequence



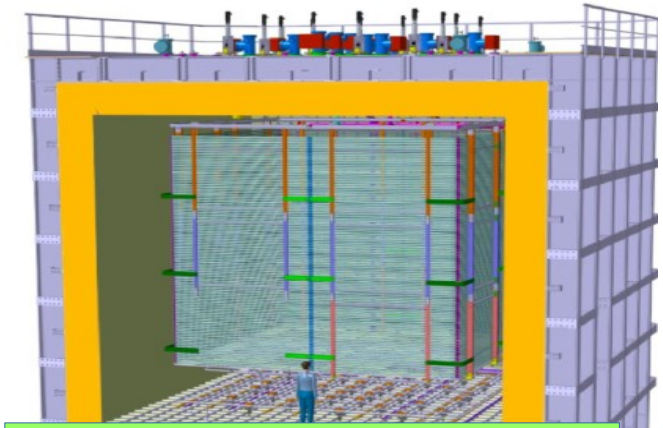
1. install internal piping & temporary floor



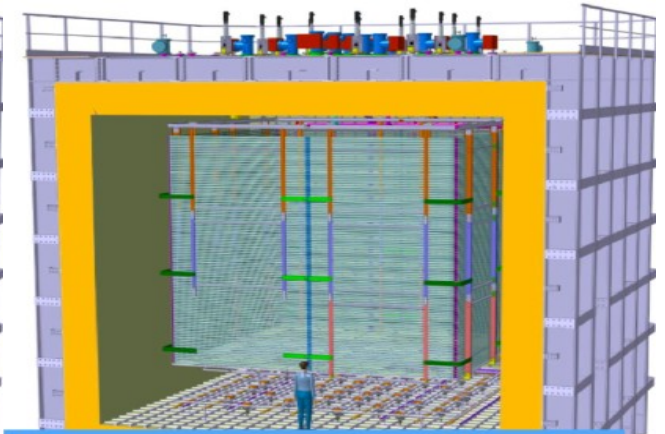
2. install the 1st drift cage modules



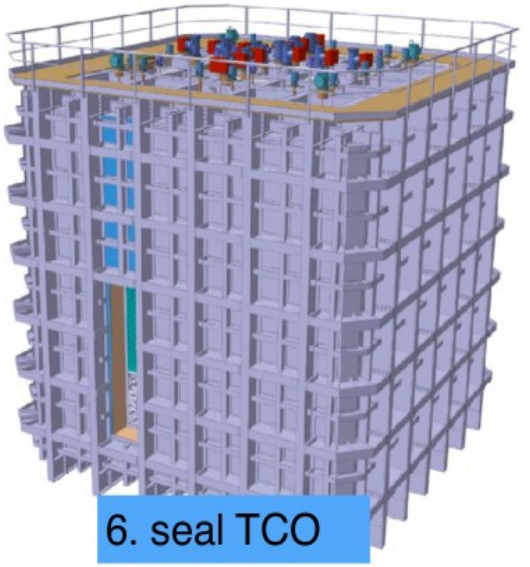
3. install the full drift cage modules



4. install CRP frames

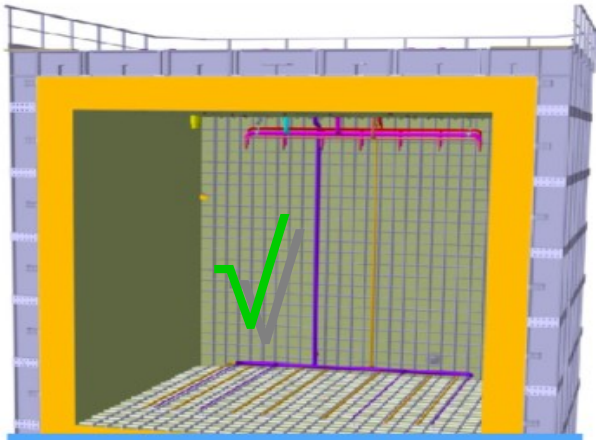


5. remove temporary floor and install photomultipliers

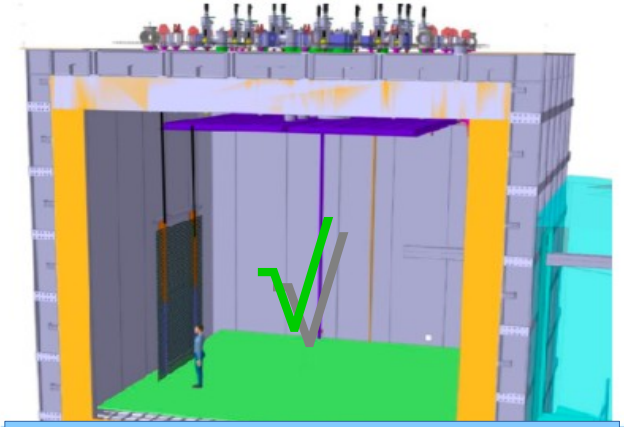


6. seal TCO

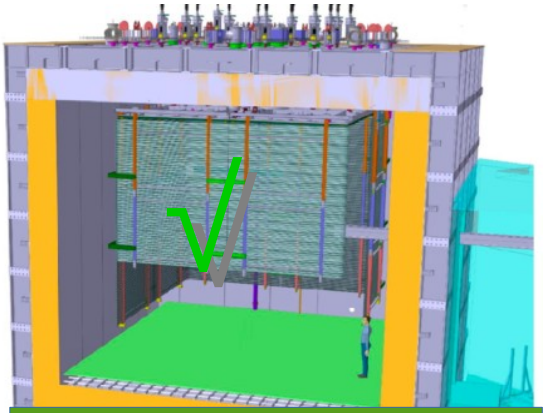
protoDUNE-DP installation sequence



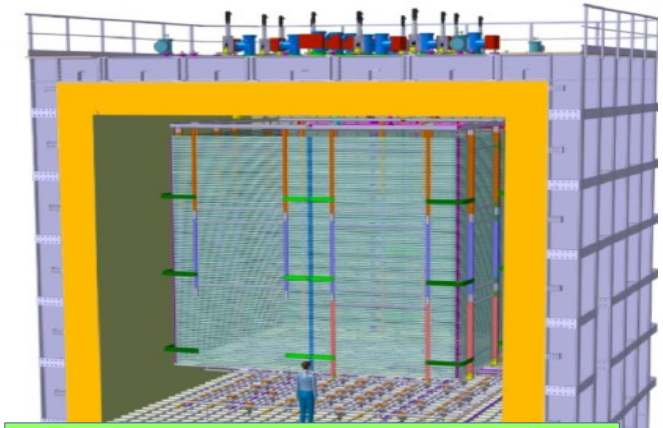
1. install internal piping & temporary floor



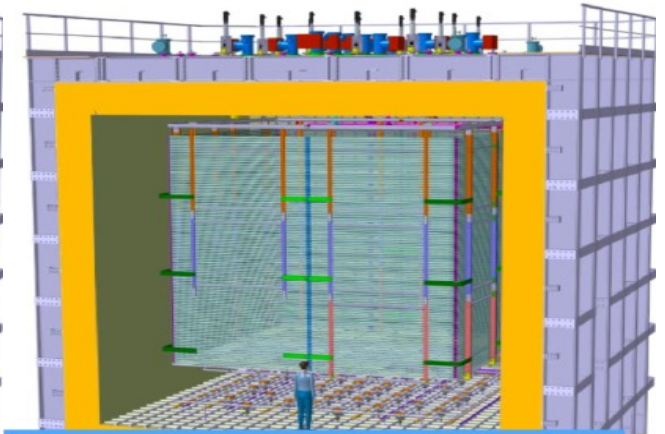
2. install the 1st drift cage modules



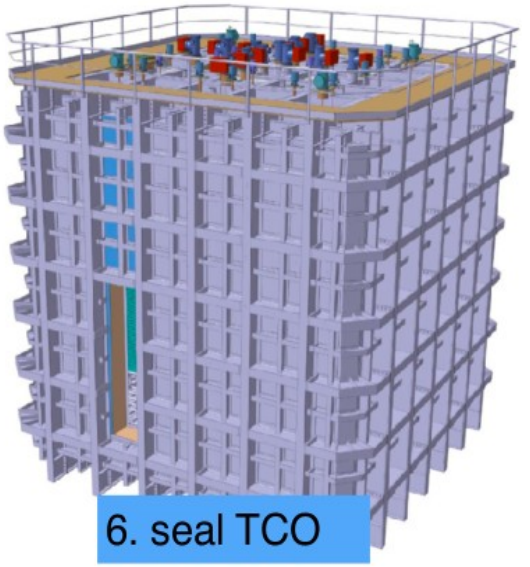
3. install the full drift cage modules



4. install CRP frames



5. remove temporary floor and install photomultipliers



6. seal TCO

Status : protoDUNE DP

Cryostat:

- Cryostat fully installed, cleaned and leak tested
- Internal cryogenics, including all feedthroughs fully installed and leak tested

Field Cage:

- Installation of all the Field cage submodules completed, electrical test completed

CRP: Cold box

- CRP cold box construction completed, leak tested.
- First cold test with LAr foreseen in coming weeks

CRP: LEM

- 28/36 LEMs for CRP1 validated so far. Expect CRP1 completed in 2-3 weeks
- LEM production for CRP2 started. Should be completed by end of June

Status : protoDUNE DP

CRP: Anode

- Anodes for first CRP produced and received at CERN, remaining are in the stage of production

Light collection system :

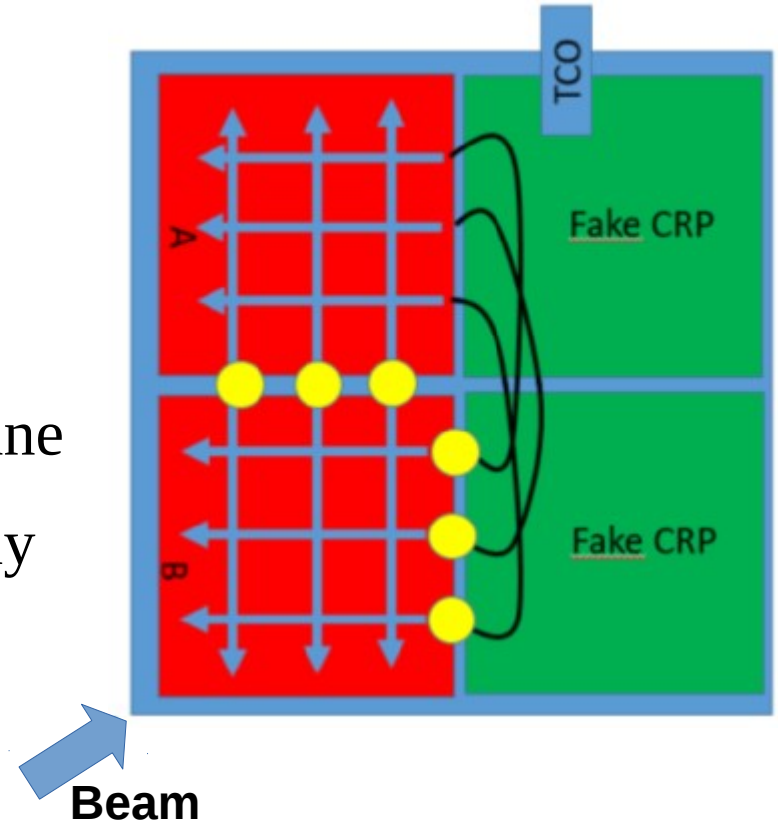
- Full characterization of PMTs completed at room and cryogenic temperature and in advanced status for installation

Front End Electronics :

- Test with pulse generator ongoing, will be ready for installation in June

Schedule and plan: protoDUNE DP

- Start of assembly CRP1 : end of April
- End of assembly CRP1 : end of May
- Cold test of CRP1 in June : (1 month)
- Installation in EHN1: July
- Start of assembly CRP2 : beginning of June
- End of assembly CRP2 : beginning of July
- Cold test: July (1 month)
- Installation in EHN1: August



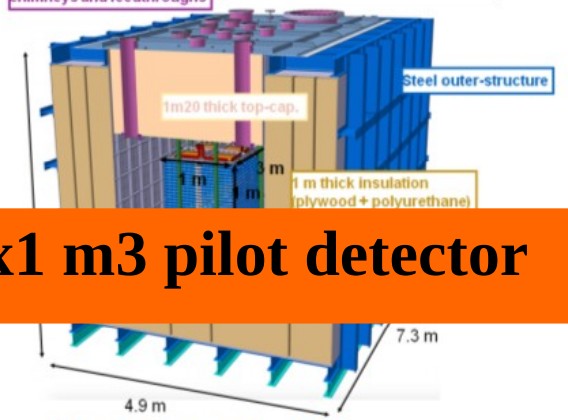
- CRPs 3&4: Fake (not instrumented with LEMs and anodes) to be prepared after July

Plan : build ProtoDUNE-DP detector with 2 active CRPs and 2 non instrumented CRP frames but with ground plates to guarantee the closure of the field lines. Goal to complete and install the detector by October

3x1x1 Dual Phase LArTPC

3x1x1 m^3 demonstrator

2014 ~ 2017



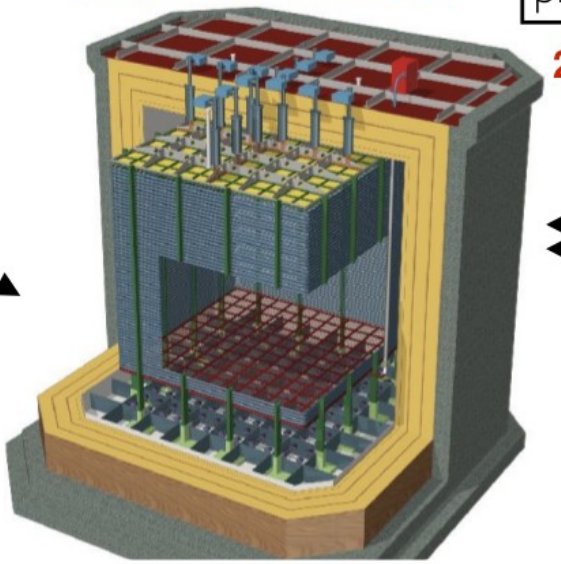
@ CERN BLDG. 182

3x1x1 m3 pilot detector

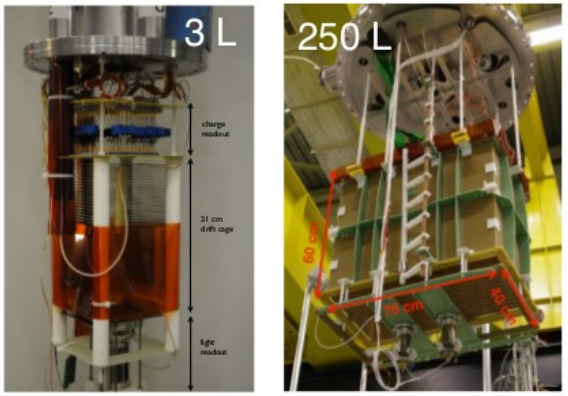
6x6x6 m^3 prototype

@ CERN IN NORTH AREA

2016 ~ 2019



Small TPCs for R&D

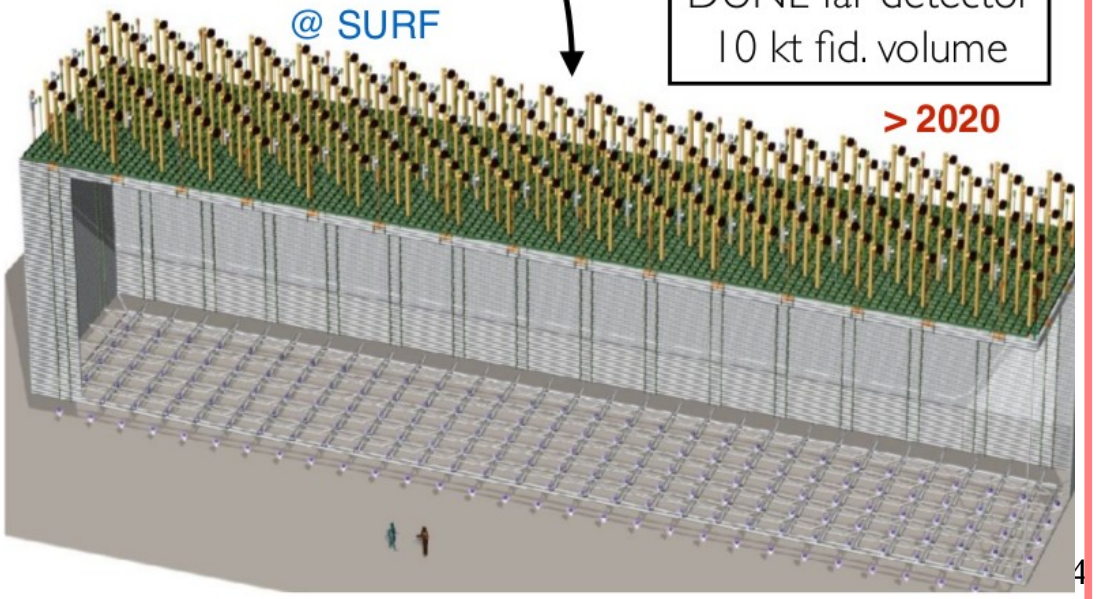


2007 ~ 2014

DUNE far detector 10 kt fid. volume

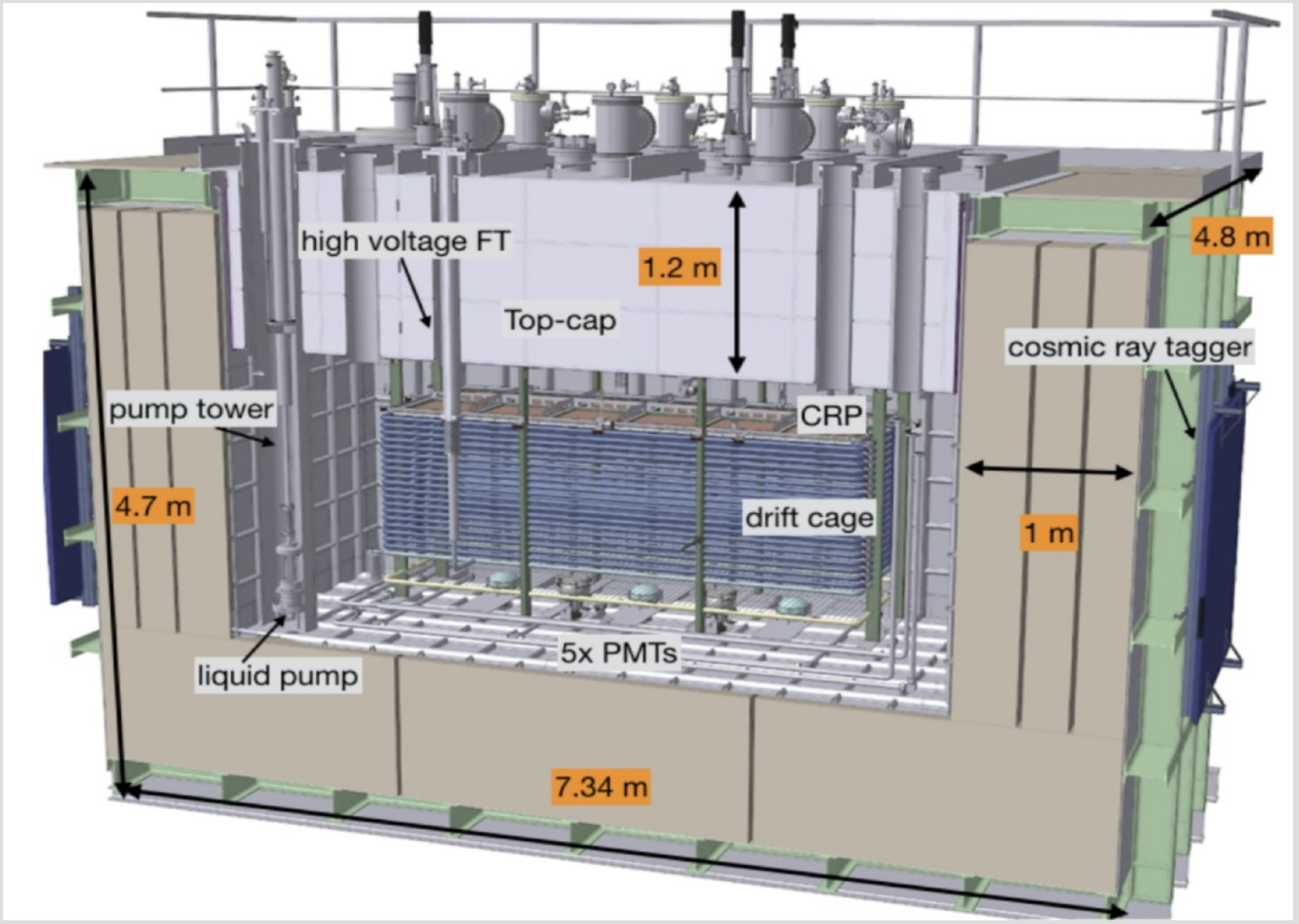
@ SURF

> 2020

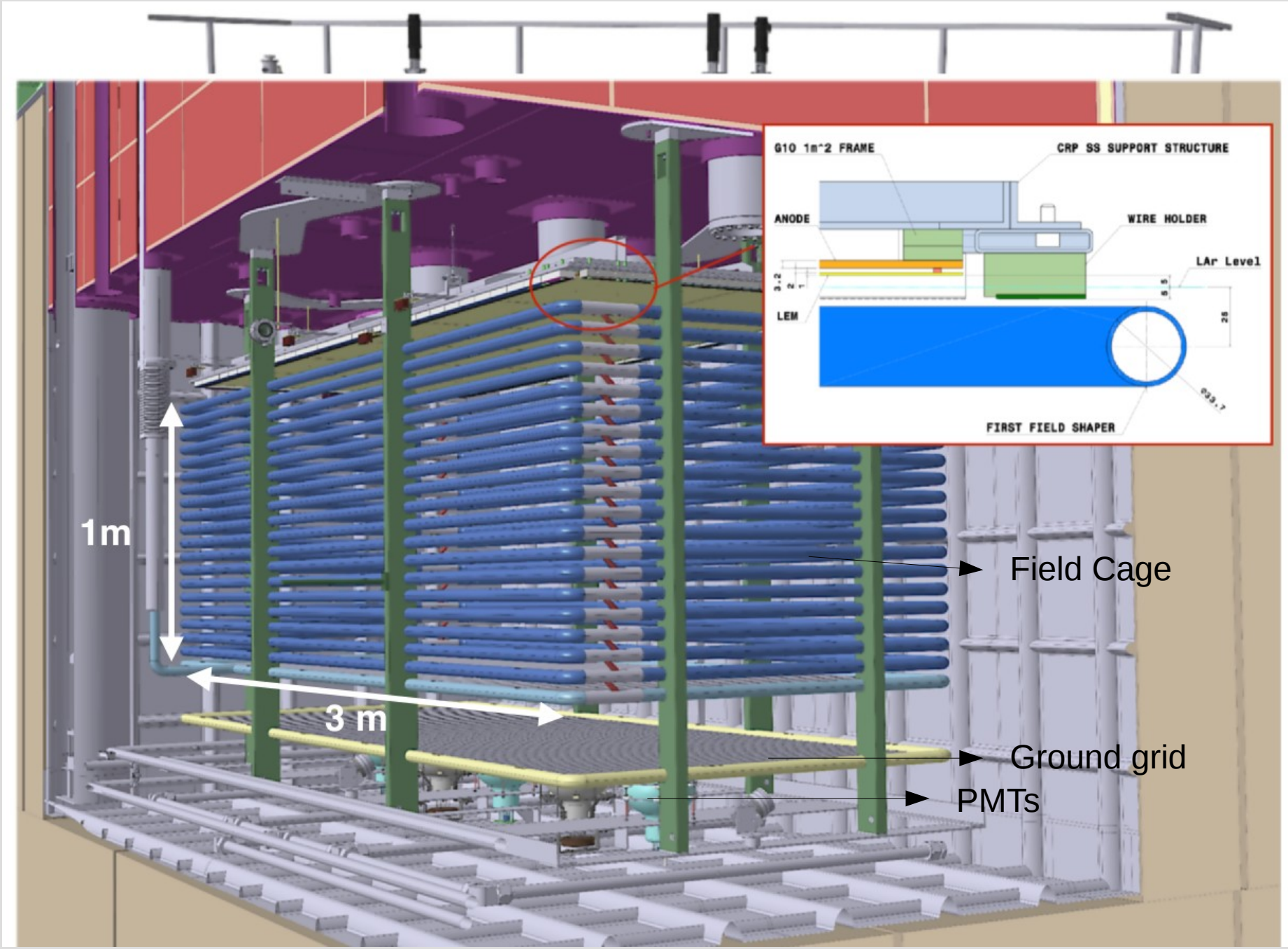


3x1x1 Dual Phase LArTPC pilot detector

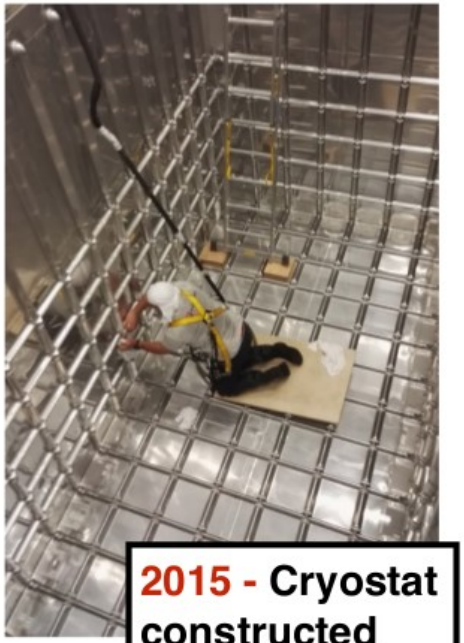
Same technology → different sizes



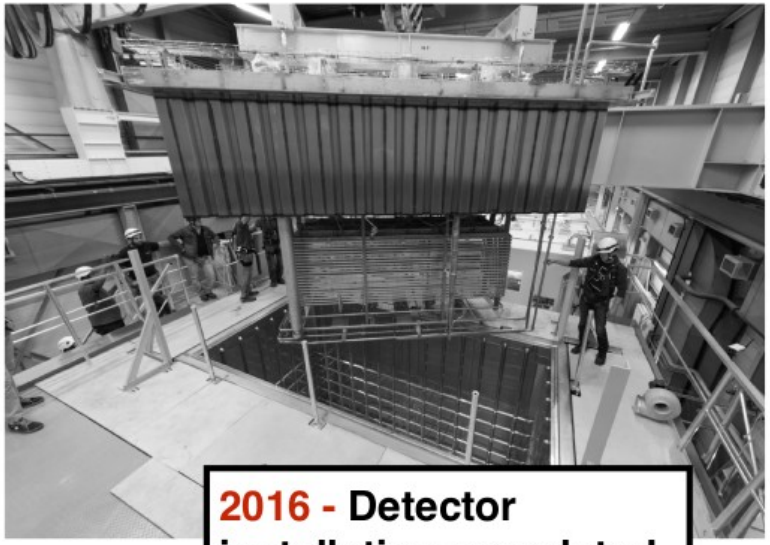
Close view of 3x1x1



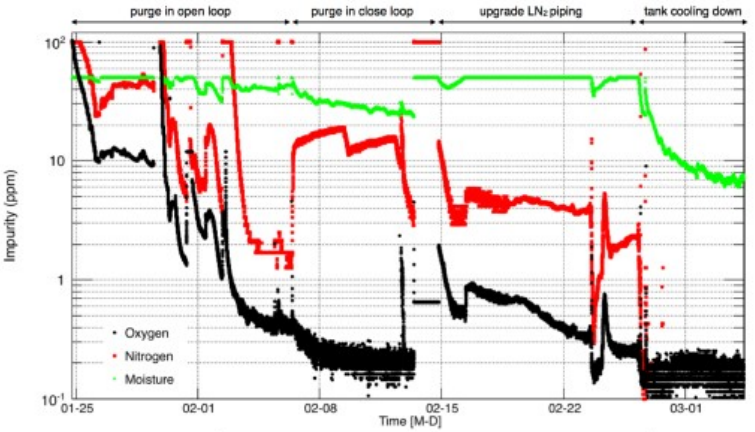
3x1x1 Timeline



2015 - Cryostat constructed

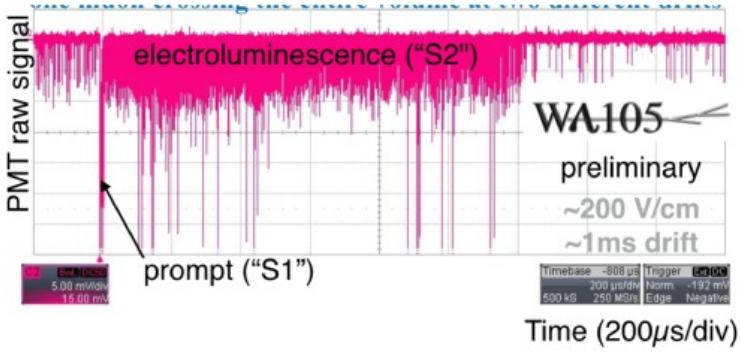


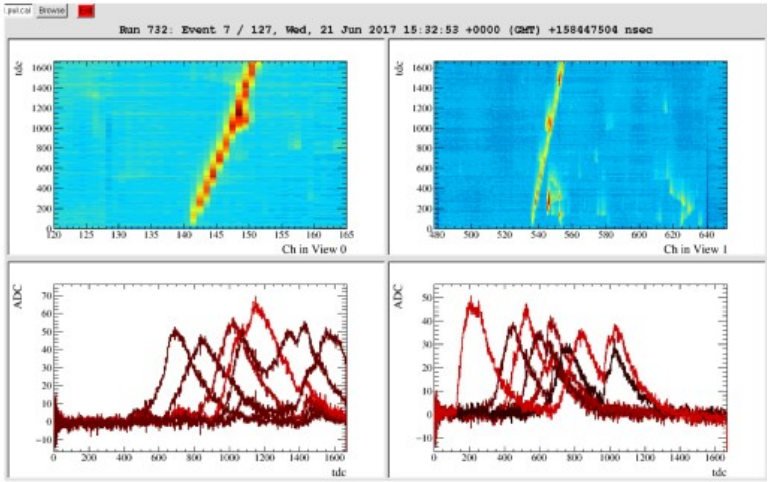
2016 - Detector installation completed



Jan 2017 - Commission started

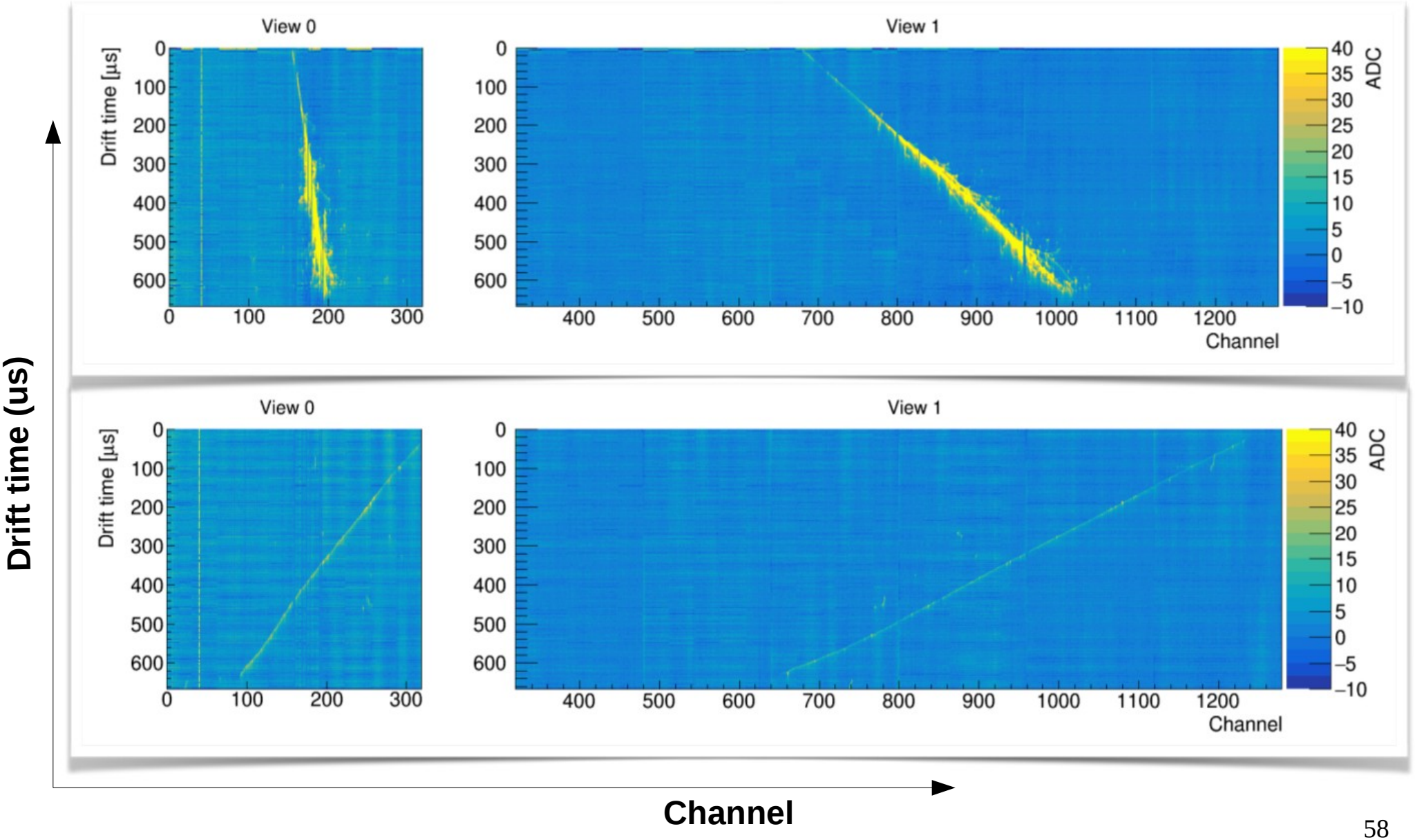
Mar 2017 - Operation 'frozen' due to cryostat issues





June 12th - Recirculation started → June 15th - evidence of extraction from LAr to GAr → June 21st 2017 - First track seen!

Two sample events



Data collection

An overall 1352 runs, 500k events taken from (June → December)

June July August September October November December

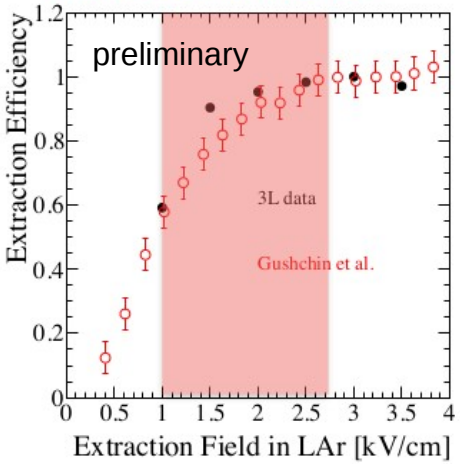
CRP alignment and HV trials

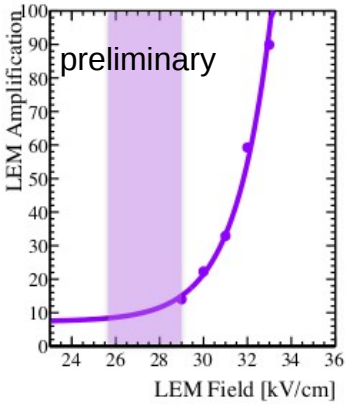
Period I: Data in different HV configurations

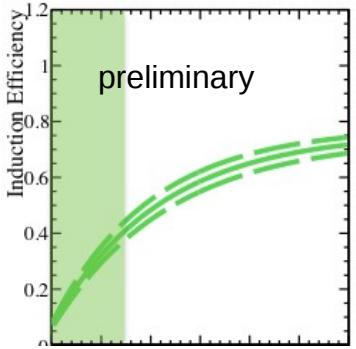
Dedicated test on Grid and LEMs

Raw data no noise filtering

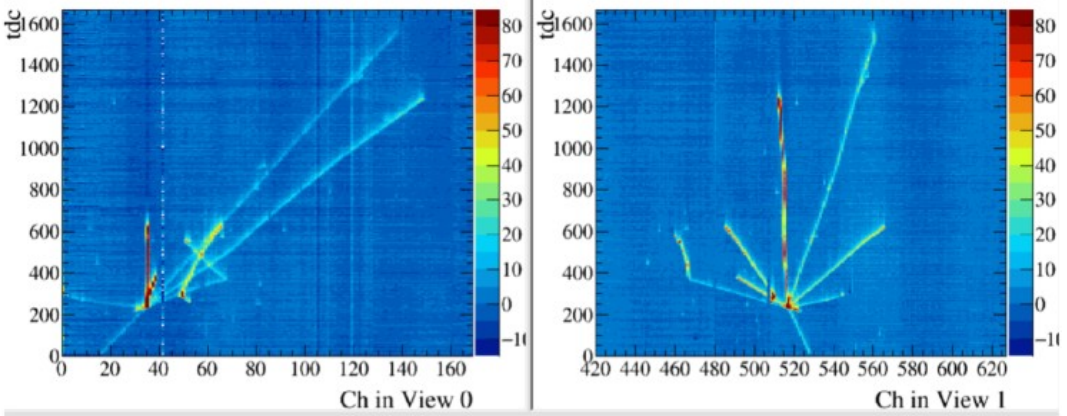
Extraction field scan

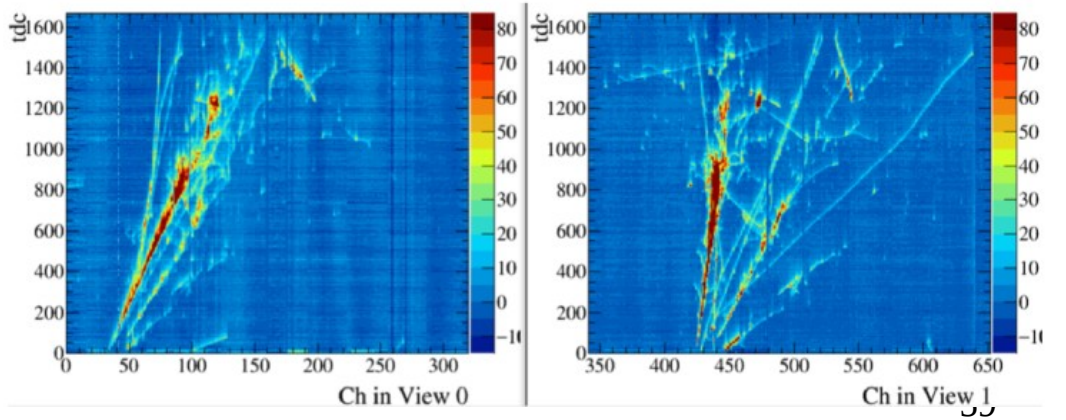


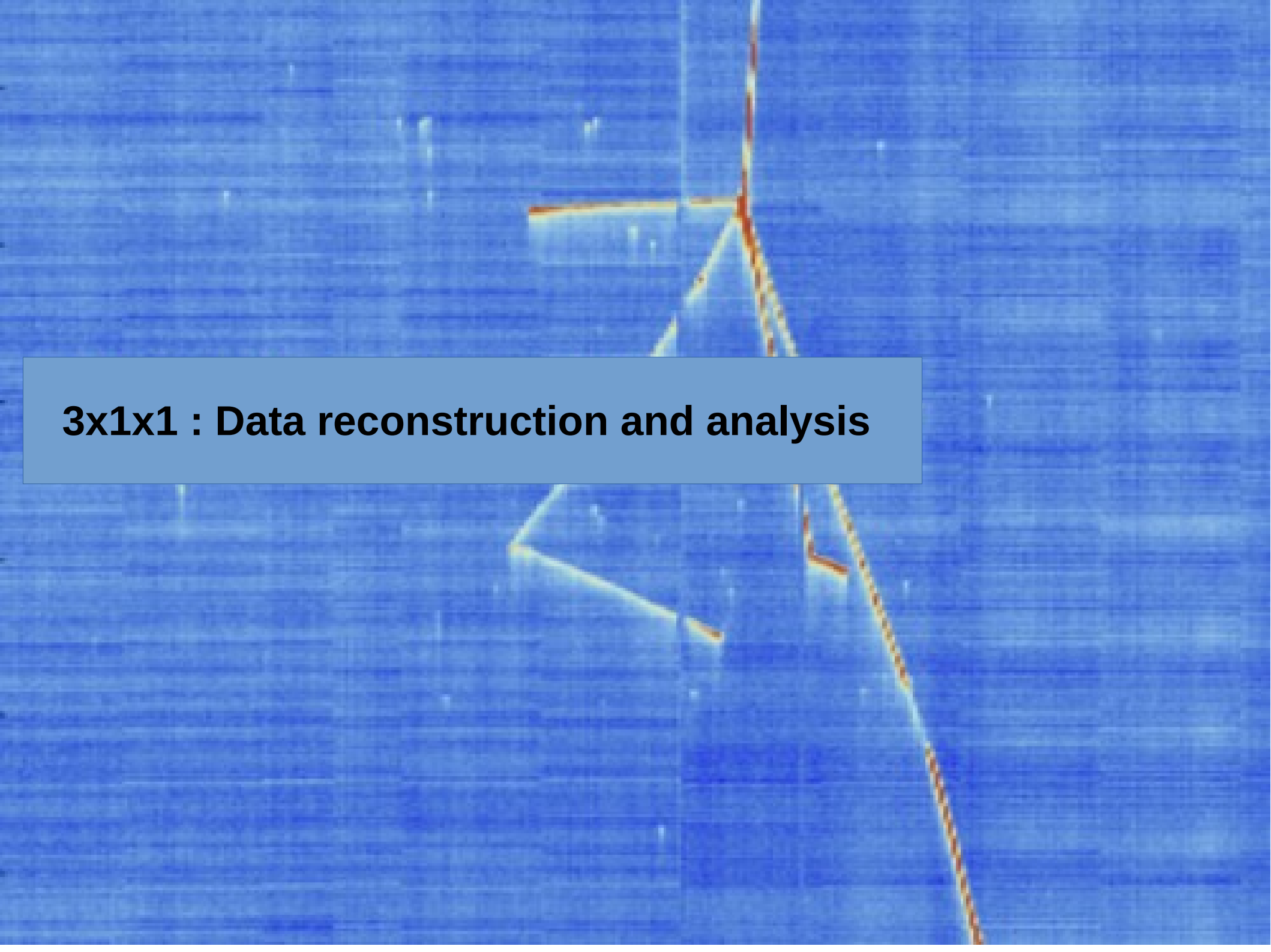




Amplification and **collection** field scan at a **fixed extraction**



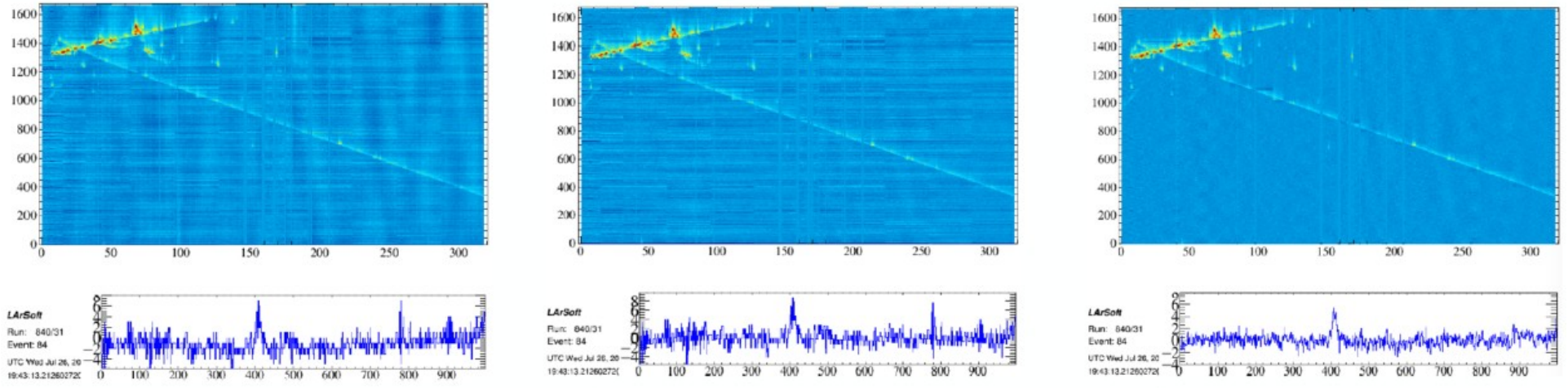


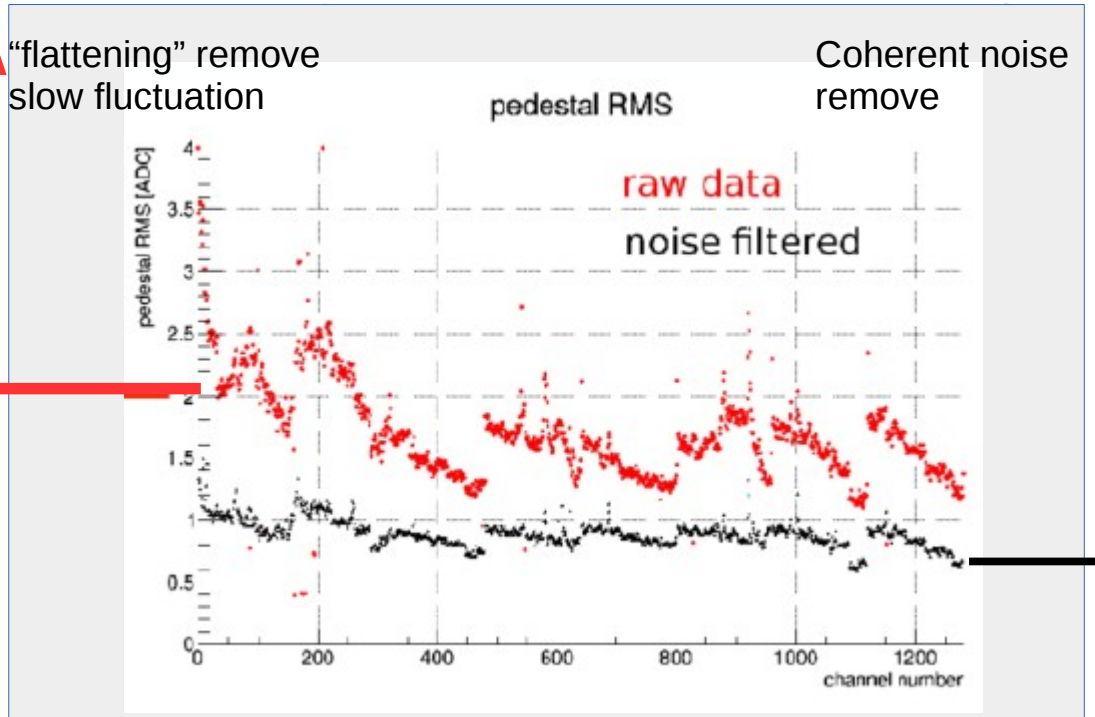


3x1x1 : Data reconstruction and analysis

Noise Performance

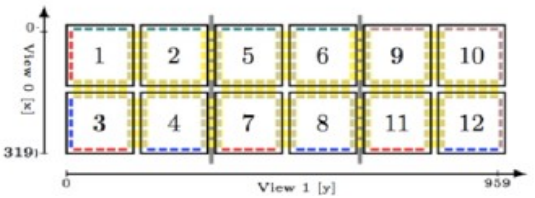
test of noise removal algorithm



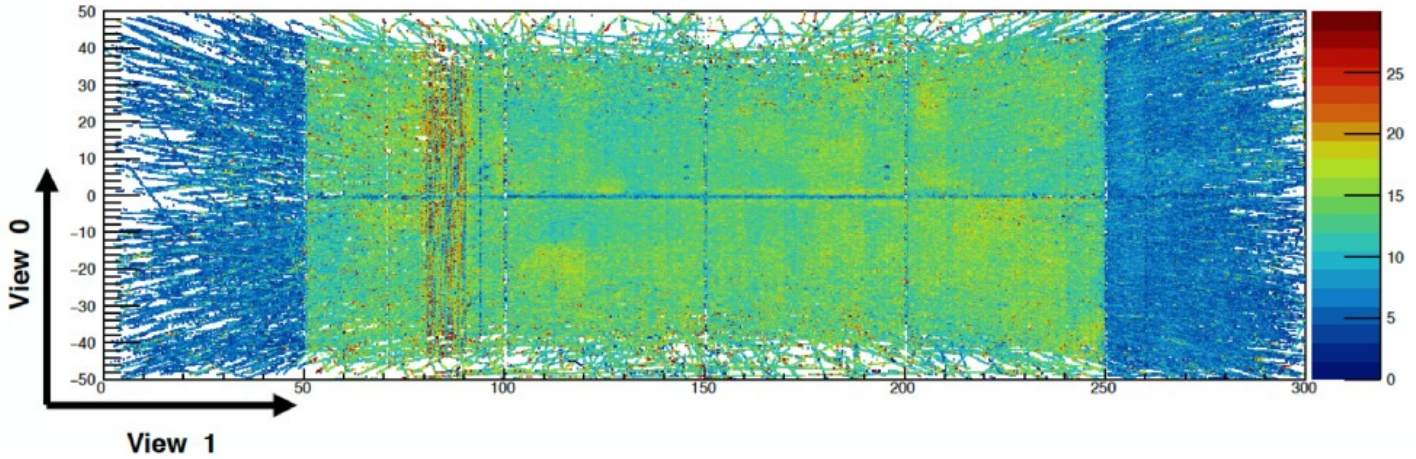


Initial look at the data : Uniformity

Run 840 : 2945 crossing tracks

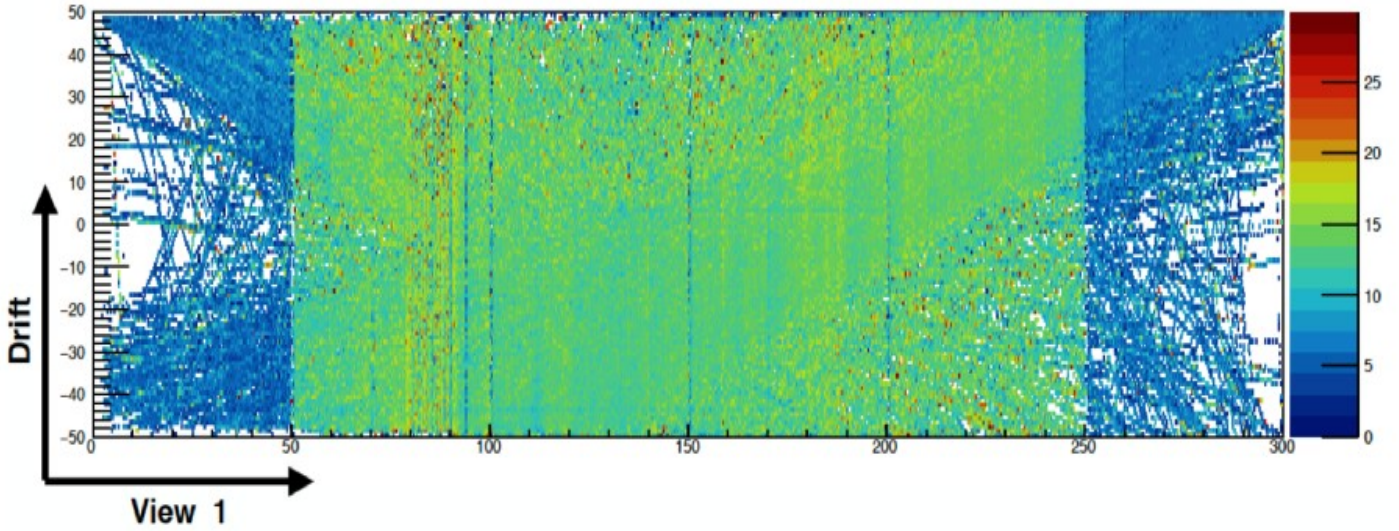


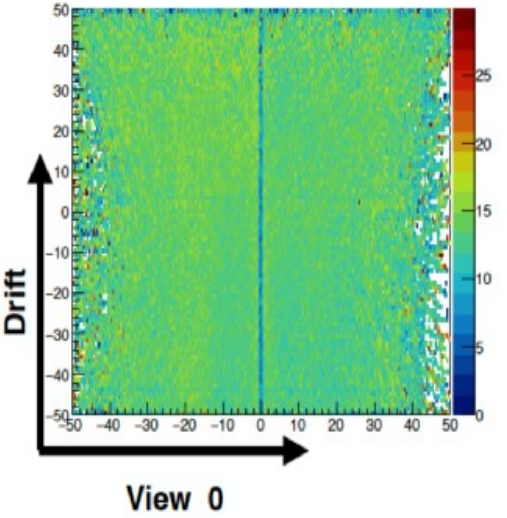
<dQ/dS> uniformity across the CRP



- Drift field : 500V/cm
- Extraction field in liquid : 1.9kV/cm
- Amplification field : 28kV/cm
- Induction field : 1.5kV/cm

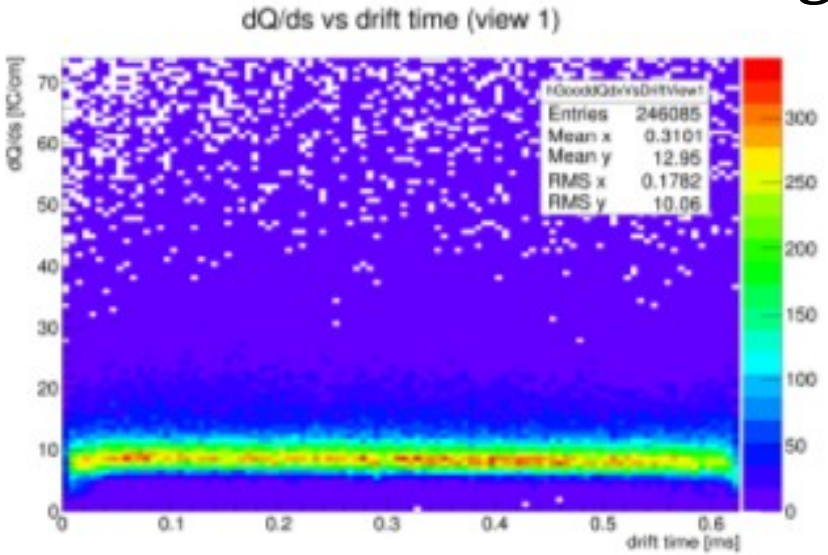
<dQ/dS> uniformity along the drift



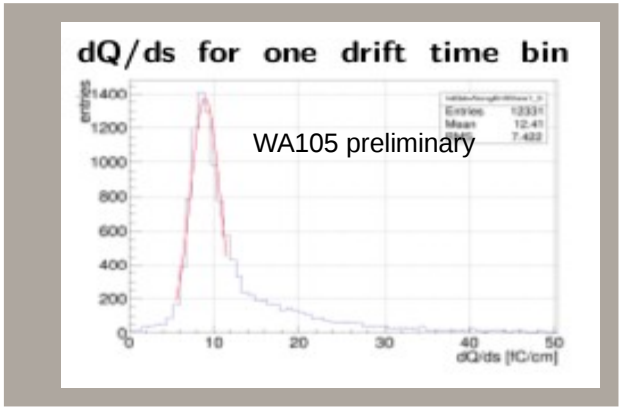


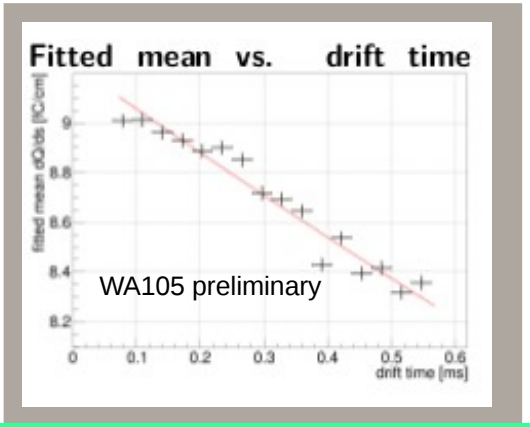
Initial look at the data : Purity (Preliminary)

Impurities in LAr such as O_2 and H_2O capture electron, electron lifetime measurement gives idea about purity of LAr



- Select through going tracks (top to bottom)
- from 3D reco: calculate dQ/ds for each hit of the track





- ✔ **Preliminary results indicate a purity compatible with ms electron lifetime**
- ✔ **Gain about a factor of 20**

Paper in preparation

Editorial Board: F.Sánchez, S. Murphy, V. Galymov, E. Mazzucato, M. Campanelli

A 5 ton demonstrator for large-scale dual phase liquid argon time projection chambers

Abstract

Keywords: Neutrino, liquid argon TPC

Contents

1. Introduction

2. The 3×1×1 m^3 as ton scale demonstrator of the dual phase liquid argon TPC

2.1. Experimental setup

The experimental setup is illustrated in Fig. 1 and some pictures are provided in Figure 2. It consists of a 3×1×1 m^3 (4.2 tons) active volume dual phase LAr-TPC inside a passively insulated cryostat with internal volume of ∼23 m^3. The entire detector is hung under a 1.2 m thick insulating lid called *top-cap*. The top cap is part of the cryostat structure providing the functionality of reducing heat input and minimizing the liquid and gas argon convection inside the tank. Altogether, twenty pipes of various diameters, called *chimneys*, cross the top cap in order to host the necessary feedthroughs as well as the interfaces to the cryogenic system. The TPC is composed of a 1 m high field cage made by nineteen field shaping rings placed at a constant spacing of 50 mm and a metallic grid cathode at the bottom. A uniform drift field is provided by a resistor divider chain situated between the cathode and the top field shaping ring. Five photo-multiplier tubes (PMTs) are mounted underneath the detector and shielded from the high voltage by a metallic grid grounded to the cryostat. They detect the scintillation light produced by charged particles crossing the LAr target (primary scintillation, S1), as well as the secondary scintillation light (S2) produced via electro-luminescence by the electrons extracted to the GAr phase [1]. They are coated with the wavelength shifter 1,1,4,4-Tetraphenyl-1,3-butadiene (TPB) [2] to detect the deep ultra

Outlook : 3x1x1 pilot detector

- First large scale DP LAr TPC was successfully operated
- We have learned valuable lessons from the 3x1x1 for protoDUNE and DUNE
- Good argon purity will allow charge drift over several 10m
- No problems with charge readout uniformity and charge sharing
- Success of 3x1x1 catalyzing progress on 6x6x6

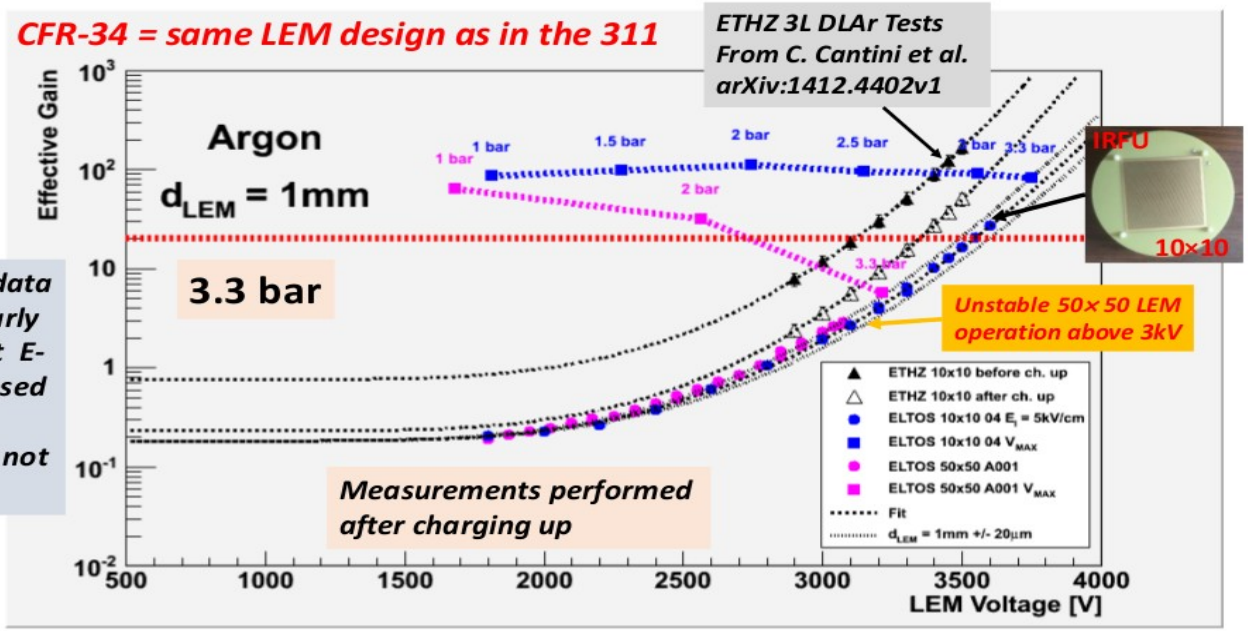
Conclusions

- Dual Phase LArTPCs are one of the far detector technology options foreseen for the DUNE experiment
- The protoDUNE Dual Phase will not only serve as the engineering prototype of the FD, but will also demonstrate the concept of large dual phase LArTPC
- The protoDUNE-DP passed final design review and PRR, in a stage of production and installation of several detector components
- 3x1x1 dual phase pilot detector successfully installed and finished taking cosmic data
- The 3x1x1 pilot detector has been extremely useful in order to reach an advanced state of prototyping and costs assessment of most of the components for the 6x6x6 and to anticipate legal and procurement problems
- The protoDUNE-DP collaboration is committed to demonstrate the Dual Phase concept at the kton scale in time-scale useful for the DUNE far detector design


Thank You

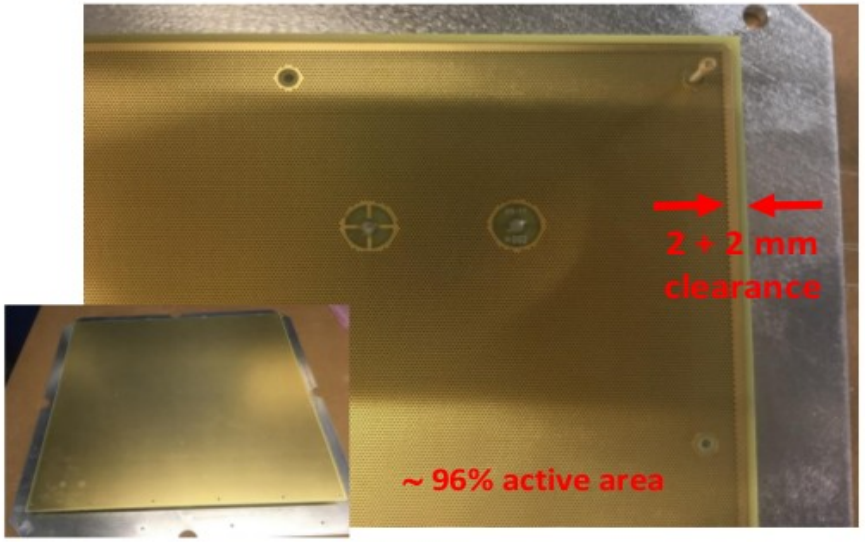
Backup

LEM: Development



Discrepancy with 3L data for HV > 3 kV not clearly understood. Different E-field configurations used and recombination effects with α source not taken into account.

CFR-34 - 311 prototype



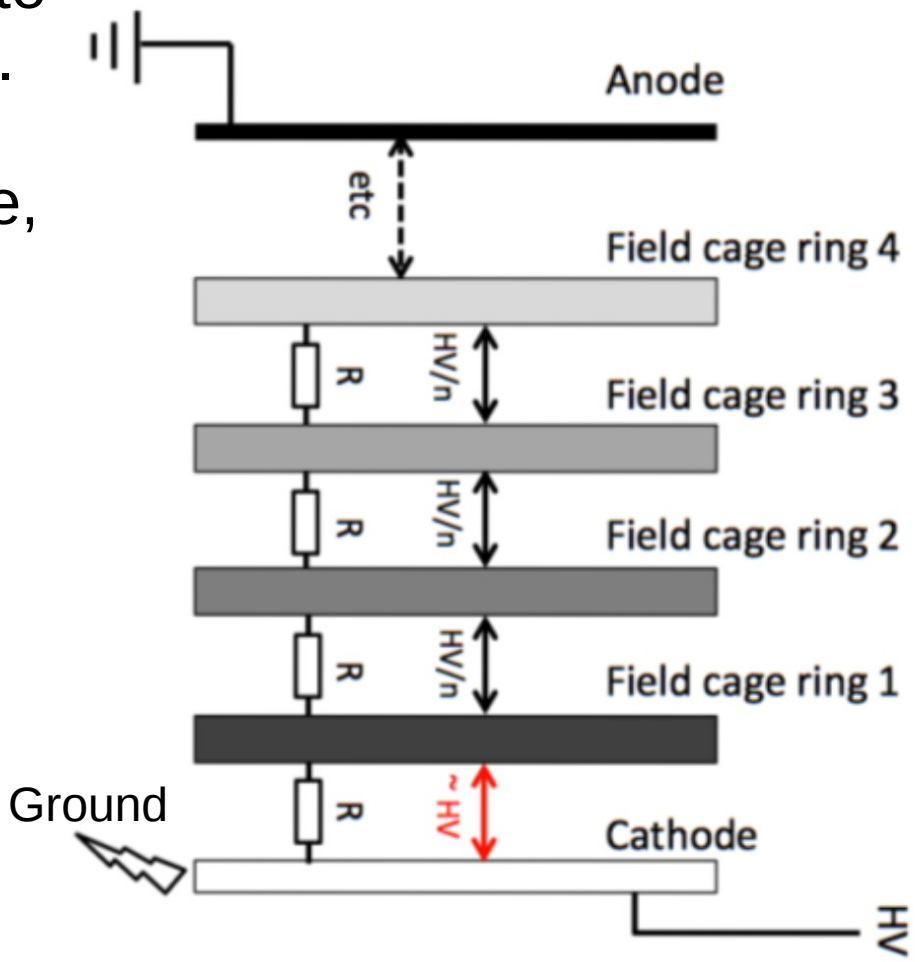
CFR-34 ΔV_{LEM} = 3.3-3.5 kV in Ar @ 3.3 bar

Before charging-up

~ 20 sparks/h (> 45% of sparks near edges or corners)

How Varistor works?

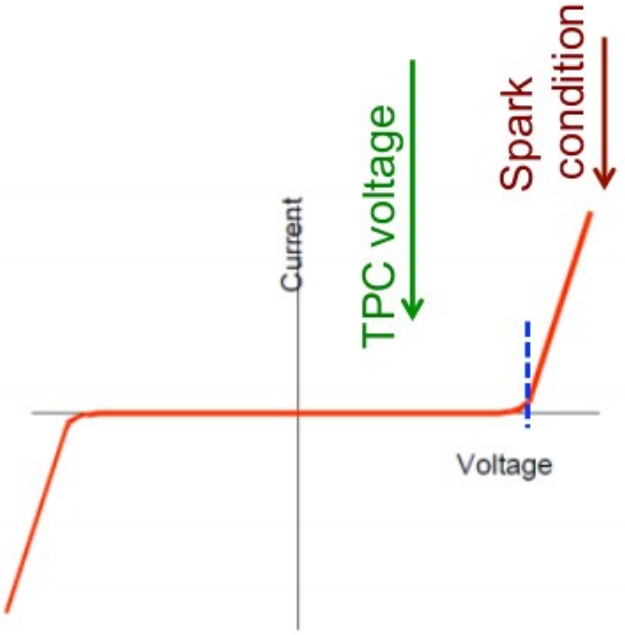
- Lets consider cathode discharge to ground (due to some breakdown).
- Field cage profile has capacitance, so remain charged.
- Large resistance prevent charge redistribution in the field cage.
- The relaxation time of a single stage is = 1 Gohm * 1 nF = 1 s.
- In this time the large voltage difference (much higher than resistors rating) will damage the resistors.
- Same thing will happen if any profile discharges.



* **Varistors : https://arxiv.org/pdf/1406.5216.pdf**

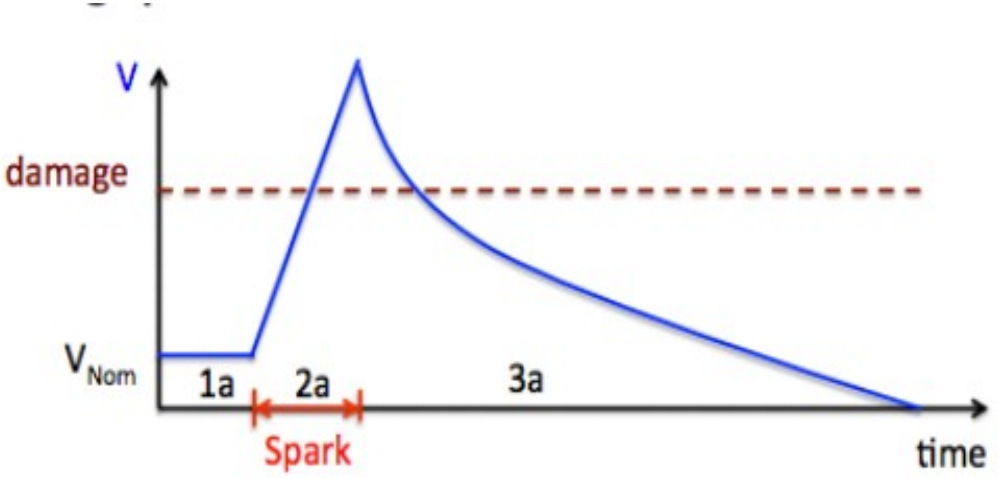
With Varistors

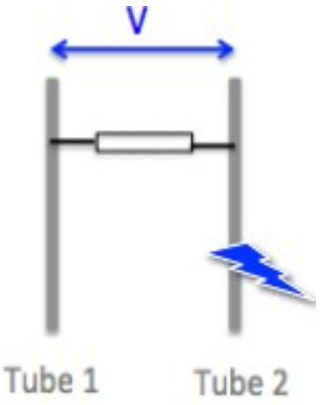
- Varistors have noon I-V characteristics.
- During the discharge, the voltage difference will be much higher than the clamping voltage of the varistors
- The resistance will go be very low and voltage will be fixed at the clamping voltage.
- The relaxation will become very less and will be redistributed quickly.



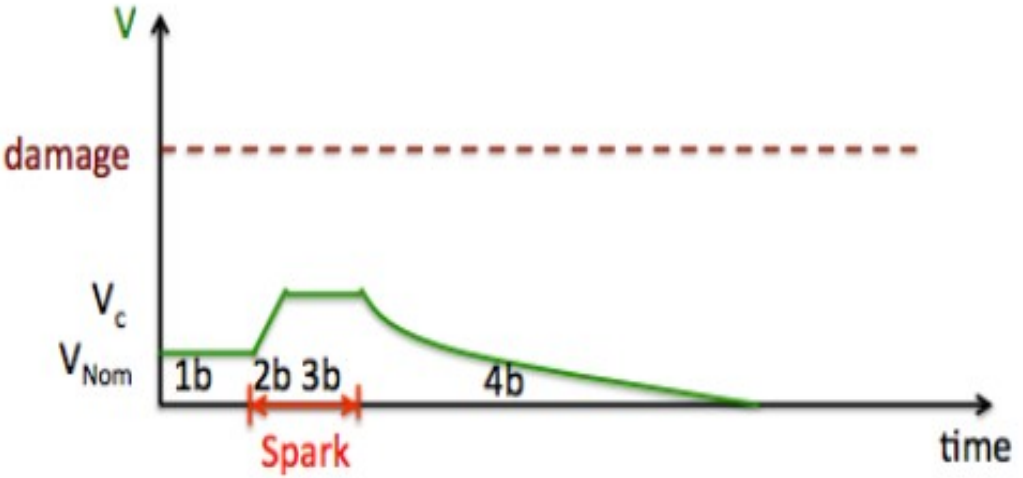
- The voltage rating of the resistor should be higher than the clamping voltage of the varistors.

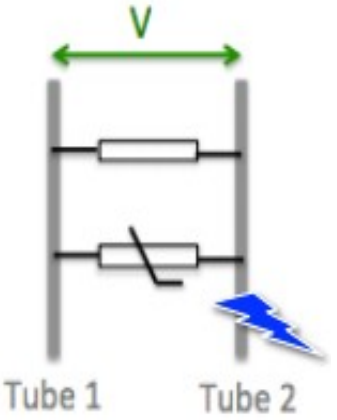
Without varistors





With Varistors

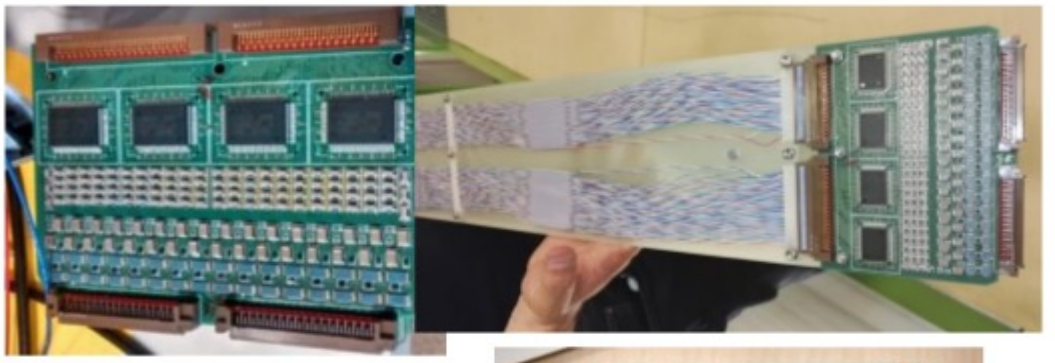




- **With the varistors, the voltage never increases than the clamping voltage.**
- **It also helps G10 and argon breakdown.**

Electronics & DAQ

Electronics components (R&D since 2006):



Analog cryogenic FE:

- Cryogenic ASIC amplifiers DP-V3 production at the beginning of 2016
- 64 channels FE cards with 4 cryogenic ASIC amplifiers
- First batch of 20 cards (1280 channels) operational on the 3x1x1 since the fall 2016
- Production of remaining 100 cards for 6x6x6 completed on 2017 budget

Digitization cards:

uTCA 64 channels AMC digitization cards (2.5 MHz, 12 bits output, 10 GbE connectivity)

- 20 cards operational on the 3x1x1 since the fall 2016
- Production of remaining 100 cards for the 6x6x6 completed on 2017 budget

White Rabbit timing/trigger distribution system:

- Components produced in 2016 for the entire 6x6x6, full system operational on the 3x1x1 since the fall 2016

Data collection

- **High bandwidth (20GBytes/s) distributed EOS file system for the online storage facility**

→ Storage servers recovered from CCIN2P3: 20 machines + 5 spares, installed at CERN on September 10th (DELL R510, 72 TB per machine) : up to 1.44 PB total disk space for 20 machines, 10 Gbit/s connectivity for each storage server.

- **Infrastructure**: DAQ rooms (to host back-end nodes/storage servers), racks, cooling, power, counting rooms → made available by Neutrino Platform in Summer 2017
- **DAQ/online storage and processing facility network architecture:**

→ Designed in collaboration with Neutrino Platform and IT, Neutrino Platform procured the 40 Gbit/s DAQ switch and 10 Gbit/s router Network infrastructure (switches/ routers). → installation completed by CERN by end of January 2018

- **Connectivity to central EOS storage at IT division:**

40 Gb/s link for ProtoDUNE-DP

- **Online computing farm:**

→ Procured by Neutrino Platform. ~1k cores installed in June in a dedicated room at EHN1 12 racks, 10 Gbit/s connectivity per rack

Latest SPSC recommendation

Dear colleagues,
thank you for the documents you sent us and the useful meeting we had on Monday. During the closed session we discussed the status of the experiment and the perspectives for 2018. In particular, we appreciate and strongly support your efforts to gain a full understanding of the problems encountered with the 3x1x1 m3 prototype. In the current SPS schedule, we maintained a 4-week beam slot for ProtoDUNE-DP in H2 (week 42-45, i.e. at the end of the proton run) but we plan to revise it as soon as the Collaboration takes decisions on the CRP's and the strategy to validate the new design. Recording data with the beam is surely valuable but, if this is not possible or introduces additional risks, we believe it is even more important to demonstrate the Dual Phase concept at the kton scale with cosmics at the beginning of LS2, namely in a time-scale useful for the DUNE Technical Design Report. We would like to be informed on the next critical decisions and your updated plan as soon as new information are available and we look forward to meeting you in April.

Collaboration reaction

The Proto DUNE-DP collaboration is committed to demonstrate the Dual Phase concept at the kton scale in a time-scale useful for the DUNE Technical Design Report, as recommended by SPSC.

Independently of the availability of the particle beam, investigate the possibility of instrumenting the 6x6x6 with two CRPs only. This enables to learn a lot on the testing and installation procedure

Setup a plan for testing the final CRPs in realistic thermodynamic conditions prior to the installation in the cryostat

Review the schedule to make it compatible with LAr filling in November 2018